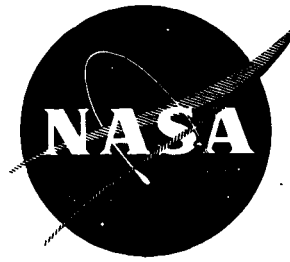


TRW INC.

INTERIM REPORT 2 OF 2

**CARBON DIOXIDE CONCENTRATION
SYSTEM**

By

A. D. Babinsky, and D. L. DeRespiris

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

March 31, 1966

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CONTRACT NAS 3-7638

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CARBON DIOXIDE CONCENTRATION SYSTEM

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ABSTRACT

The work completed under contract NAS 3-7638 during the second four-month period of the contract is reported.

Plating of components for the Stage I and Stage II cells was completed. Design and fabrication of the Stage III cell was completed. This cell, designed for use with an acid electrolyte, consists of PVDC cell end plates with gold plated copper current collector grid inserts. The end plates are clamped together by two magnesium pressure back-up plates.

Numerous changes and modifications were made in the test rig to achieve the desired control of cell operating parameters and to obtain the required experimental data.

A continuing test program on a small Stage III acid cell was conducted with a gold plated magnesium test cell. These tests were conducted to examine the acid cell polarization time-dependence and continue the materials compatibility study.

Parametric testing of the Stage I cell was completed. The effect of cell temperature, cell current density and cathode gas flow rate on cell potential was determined. Cell temperature was varied from 90°F to 140°F, cell current density from 15 amps/ft² to 46.5 amps/ft², and cathode gas flow from stoichiometric CO₂ flow to five times stoichiometric CO₂ flow.

Assembly of a Stage II cell has been completed and pressure checked. Parametric testing of the Stage II cell and assembly of the PVDC Stage III cell are in progress at this writing.

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CARBON DIOXIDE CONCENTRATION SYSTEM

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SUMMARY

Plating of components for two Stage I and two Stage II cells was completed. A Stage III cell was designed and fabrication of components was completed. The cell consists of PVDC cell end plates, gold plated copper current collectors, and magnesium clamping plates for maintaining an equal pressure distribution across the cell electrode-matrix interface.

To provide proper control of cell operating parameters and to obtain desired test data, numerous test rig modifications were completed. Major changes were; addition of another vacuum pump to increase flow capacity, provision of condensers in all gas outlet lines, additional heater capacity in the Stage I humidifier, and provision for operation of the gas analysis equipment at ambient pressure.

Two tests (M-1 and M-2) were completed on a small gold plated Stage III test cell. These tests are part of a continuing program on the acid stage cell. The object of these tests is to examine the acid stage polarization time dependence and materials compatibility. During test M-1, a 58 hour run, the rate of voltage increase over the last 27 hours was approximately 0.75 mv/hr, with the rate decreasing to 0.62 mv/hr for the last eight hours. Test M-2, a 194 hour run, used an 80% O₂, 20% CO₂ feed for the first 26 hours and pure O₂ for the balance of the run. During the sixty-five hour period from 77 hours at load to 142 hours at load, the average rate of voltage increase was 0.15 mv/hr while from that point to the end of the test the terminal voltage decreased. Additional tests were initiated and are underway at this writing.

Parametric testing of the Stage I cell was completed. The duration of each test at the various operating conditions was approximately four hours. The cell was operated at 90°, 115°, and 140°F for three current densities at each

temperature, 15, 30, and 45 ASF. The one exception being that 30 ASF was the upper limit at the 90°F cell temperature. For these runs the cathode gas flow rate was held at two times stoichiometric CO₂ at the operating cell current. One run was made at a cathode flow of five times stoichiometric CO₂ flow. Additional short term runs were made at stoichiometric CO₂ cathode flow. Cell performance is summarized below.

Stage I Cell Operating Potential

	<u>T_c ~ 90°F</u>	<u>T_c ~ 116°F</u>	<u>T_c ~ 140°F</u>
<u>2 x S Flow</u>			
I ~ 15 ASF	1.22	1.10	0.93
I ~ 30 ASF	1.53	1.30	1.13
I ~ 45 ASF	--	1.52	1.25
<u>5 x S Flow</u>			
I ~ 30 ASF	--	1.40	--
<u>1 x S Flow</u>			
I ~ 30 ASF	--	1.22	1.08

Assembly of the Stage II cell has been completed and the cell has been shown to be sealed satisfactorily internally and externally. Installation of the cell into the test rig is in progress as is the assembly of the Stage III PVDC cell.

1.0 INTRODUCTION

This is an Interim Report covering the second four months of work carried out at TRW Equipment Laboratories under Contract NAS 3-7638. The objective of this contract is to obtain parametric test data and life test data on electrochemical carbon dioxide concentration cells used in a carbon dioxide concentration system developed by TRW. The cells are large in size so that no problems of "scale-up" will be encountered in the design of a prototype system using the cell test data.

During the first four months of the program, work accomplished included:

1. Preliminary system design
2. Detailed cell design
3. Test rig design
4. Cell fabrication
5. Test rig assembly and checkout
6. Acid cell materials screening and test program
7. Small cell testing

Photographs of unplated cell components were included in Interim Report No. 1. Figure 1-1 shows two pieces of cell hardware after the completion of the plating process including the thin electroless gold layer. The Stage I cathode end plate shown has the rectangular shaped, undercut, lightening holes. This configuration provides a 20% lighter weight piece, but the machining time associated with the process is too high. Thus all other end plates have the round drilled lightening holes as shown in Interim Report No. 1.

During the last reporting period, the major effort was in establishing suitable test rig operation, and subsequently, the parametric testing of the Stage I cell. Additional effort on small cell testing also was expended.

Assembly of the Stage III cell was completed and the Stage III PVDC cell assembly is in progress.

Test results obtained to date with the Stage I cell are in all cases better than the results achieved with small plastic cells in past TRW programs.

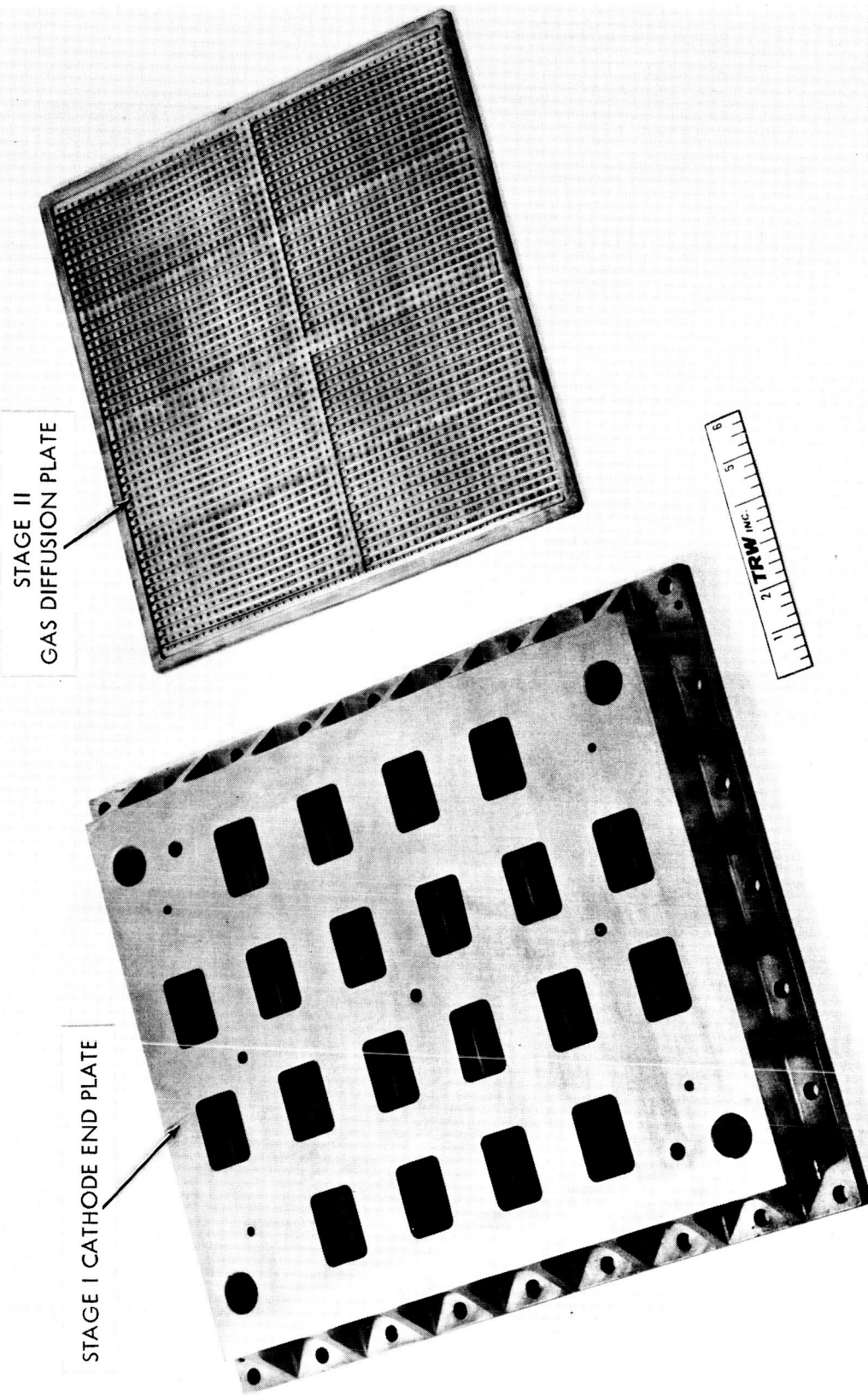


FIGURE 1-1 STAGE I & II CELL COMPONENTS - GOLD PLATED

2.0 TEST RIG CHECKOUT AND MODIFICATION

Upon completion of the test stand, a functional checkout was initiated. Control of the three thermal enclosures was maintained to within less than 1°F of the selected temperature (up to 160°F). The Stage II and III humidity control of inlet gases was satisfactory, maintaining a preset humidifier tank temperature to within 1°F of the set point temperature at rated gas flows. Testing of the Stage I humidifier indicated a need for:

1. Additional vacuum pump capacity to give the desired air flow rate at 10.0 psia. (A second vacuum pump was installed in parallel with the original pump.)
2. A higher capacity heater in the humidifier tank. (The original heater was converted to a 440 volt heater, approximately doubling the power output.)
3. A condenser to remove water from the air stream before it entered the vacuum pumps. (A gas-liquid heat exchanger with provision for condensate drain in the air side was installed between the cell and the vacuum pumps.)

The dew point temperature of gas out of the humidifier was checked with a Foxboro Dew Point Analyzer, correlating to within 2°F of the tank temperature. A check also was made on the amount of water removed from the condenser to check the accuracy of the Foxboro data.

During the first test runs with the Stage I large cell, a number of difficulties in operation of the test rig were encountered. The difficulties and corrective measures taken were as follows:

1. The pressure drop across the sparger plate in the humidifier gradually increased with operating time until it was impossible to achieve significant flow of air through the humidifier and cell. Due to the passage of carbon dioxide in the inlet air through the hot tap water, a carbonate type of deposit was forming in the sparger plate. The humidifier was removed from the rig and cleaned with acid and water to remove the

deposit. After reinstallation of the humidifier tank a distilled water feed system was installed to avoid further formation of water insoluble deposits.

2. Setting air flow rate and cell operating pressure was difficult and time consuming. Trim by-pass valves were installed in parallel with the flow control valve and back pressure regulator valve.
3. Additional capacity in condensate storage was required. Two parallel storage bottles with shut-off valves were installed.
4. Water was condensing in the anode gas sample outlet line and the dew point sample outlet line. Condensers and collector bottles were installed in these lines to remove unwanted condensation in test sample lines.
5. Varying water level in the humidifier tank was causing the dew point temperature out of the humidifier tank to vary. An automatic water level control was added to the distilled water feed circuit.
6. Gas inlet lines to the cathode and gas sample lines to the dew cell chamber were running at temperatures below the cell operating temperature. Controlled heater tapes and insulation were added to lines where required.
7. Difficulties in sampling cathode and anode gases below atmospheric pressure were encountered with the oxygen analyzer, wet test meter, and CO₂ analyzer. The anode was replumbed to operate at ambient pressure and a vacuum pump was installed to draw gas samples from the cathode chamber.

8. Erratic readings of dew point temperatures were obtained from the "Dew Cell" sampling element. The element was removed from the rig, and tested and calibrated over the expected operating range.

Numerous other minor changes and modifications were made to improve the performance of the test rig and recording instrumentation.

3.0 SMALL CELL TESTING

Based on the materials screening program reported in Interim Report No. 1, a gold plated magnesium cell was selected for further evaluation in the small cell test program.

3.1 Cell Description

The gold plated magnesium cell end plates are shown in Figure 3-1. Slight discolorations on the land areas are due to operation in the water bath during tests M-1 and M-2. This cell contains in the end plates an integral pin and baffle structure. Design characteristics of the pins are similar to the large cell units. The active electrode area contained by these cells is 0.0775 ft².

A compilation of the materials used in the cell is given in Table 3-1.

TABLE 3-1
GOLD PLATED MAGNESIUM ACID CELL MATERIALS

<u>Component</u>	<u>Material</u>	<u>Remarks</u>
End Plates	AZ31B Type 2 Magnesium Plate	Gold Plate as follows: a) Zinc immersion (molecular) b) 0.1 to 0.3 mil copper c) 1.5 mil nickel d) 1.5 mil electrolytic gold e) 0.5 mil electroless gold
Electrodes	American Cyanamid Type - AA1	Tantalum screen with 9 mgm/cm ² of platinum
Electrolyte Matrix	Matted Structure	Whatman GFB glass fiber filter paper - (20 mils thick)
Gasket	Viton	

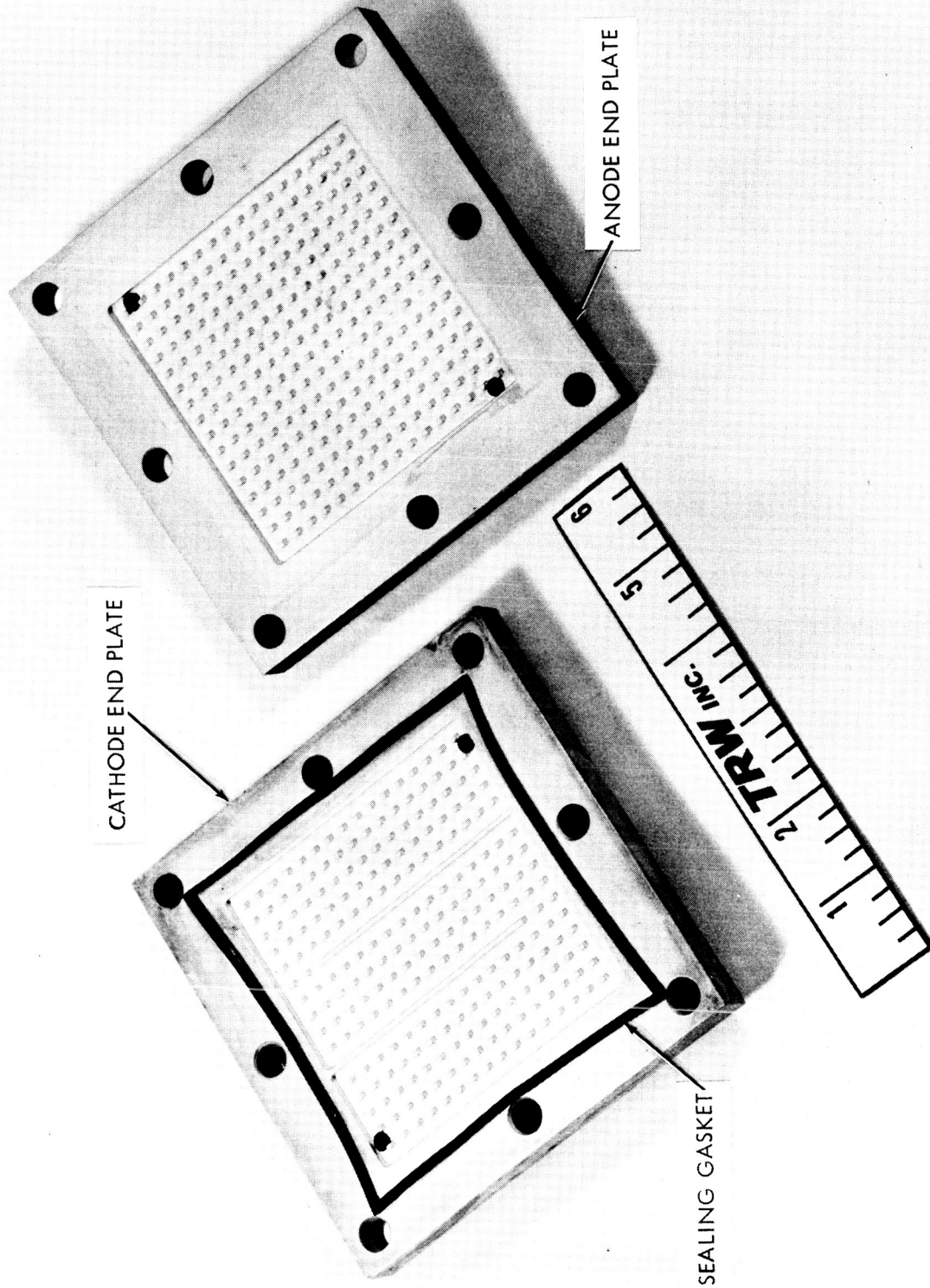


FIGURE 3-1 GOLD PLATED MAGNESIUM ACID STAGE TEST CELL

3.2 Test No. M-1

Figure 3-2 shows the polarization time dependence obtained during the first experimental run with the gold plated magnesium cell. The total time at load for the test cell was approximately 58 hours. A break in performance, as indicated by the discontinuity, occurred at the end of six hours when the constant current power supply failed. The cell was returned to load with a new power supply and continued operation for another 52 hours. The test was terminated due to an internal gas leak caused by improper seating of an electrode resulting in matrix damage. Over the last 27 hours of the test the average rate of voltage increase was approximately 0.75 mv/hr, with the rate decreasing to 0.62 mv/hr over the last eight hours. It can thus be seen that the rate of increase in voltage was still decreasing with time. A post-test cell inspection revealed no corrosion of the end plates.

3.3 Test No. M-2

Using new electrodes, the cell was reassembled in preparation for a repeat of the previous test for a longer time period. Initial operating conditions were identical to those of test run No. M-1. The polarization time dependence for the run is plotted in Figure 3-3.

Initial cell voltage was 0.932 volts, rising to 1.100 volts after three hours of operation. At the end of twenty-six (26) hours of operation, the cell terminal voltage was 1.186 volts. Over the last four and one-half hours, the average rate of voltage increase was 1.78 mv/hr. At this time, the CO₂ was removed from the cathode feed to see if the CO₂ actually was contributing to the cell degradation. Oxygen was used as the cathode feed for the balance of the test.

After switching to O₂ feed, the initial cell terminal voltage was 1.058 volts increasing rapidly (30 minutes) to 1.085 volts, then following a rate of increase close to the rate observed before the CO₂ was removed from the cathode feed. In addition to the periods of increasing cell voltage, periods of stable cell voltage and decreasing cell voltage were noted. During the sixty-five hour period from 77 hours at load to 142 hours at load, the average rate of voltage increase was 0.15 mv/hr, while from that point to

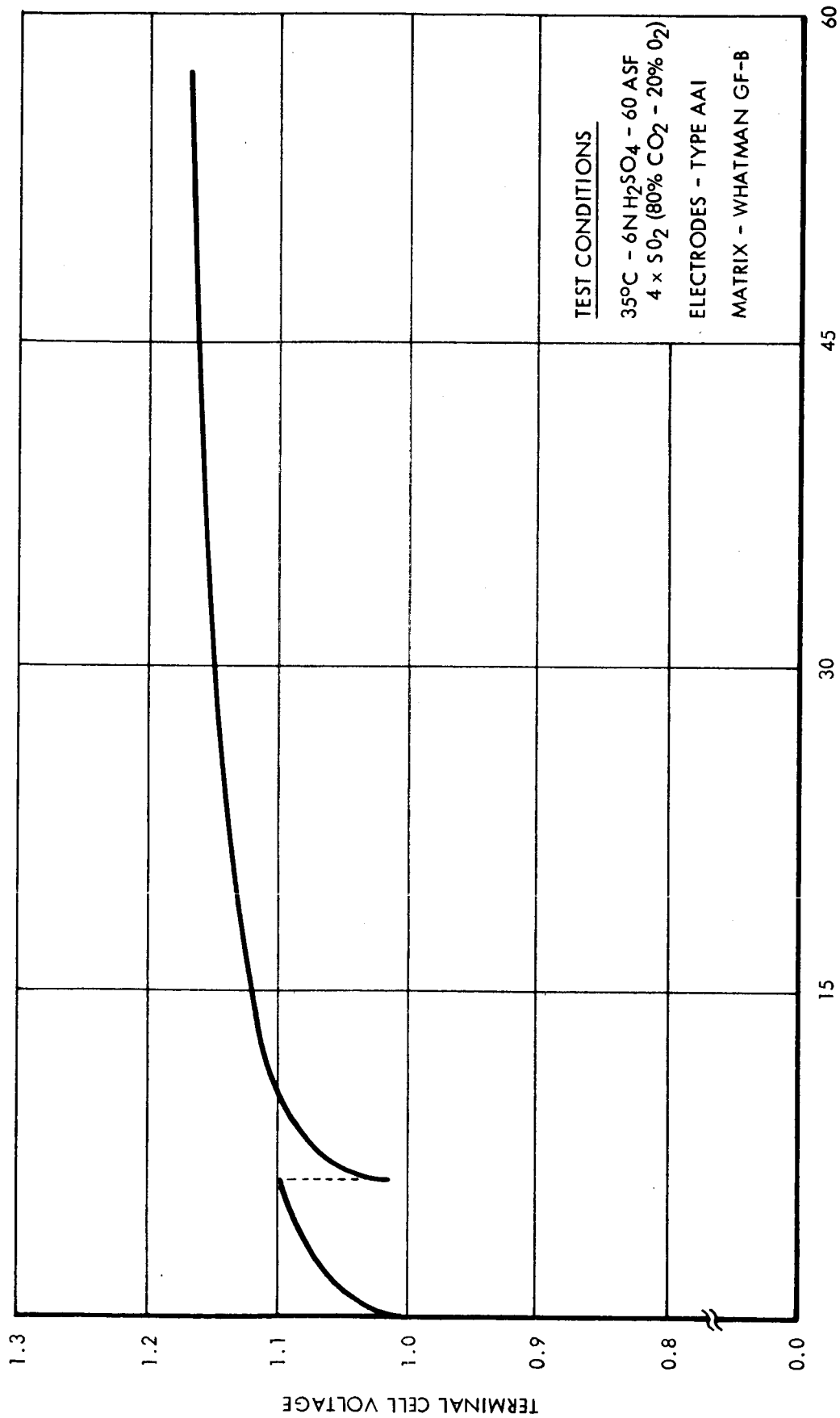


FIGURE 3-2 POLARIZATION TIME DEPENDENCE - STAGE III - TEST #M-1
 (CELL TYPE MG/Ni/AU)

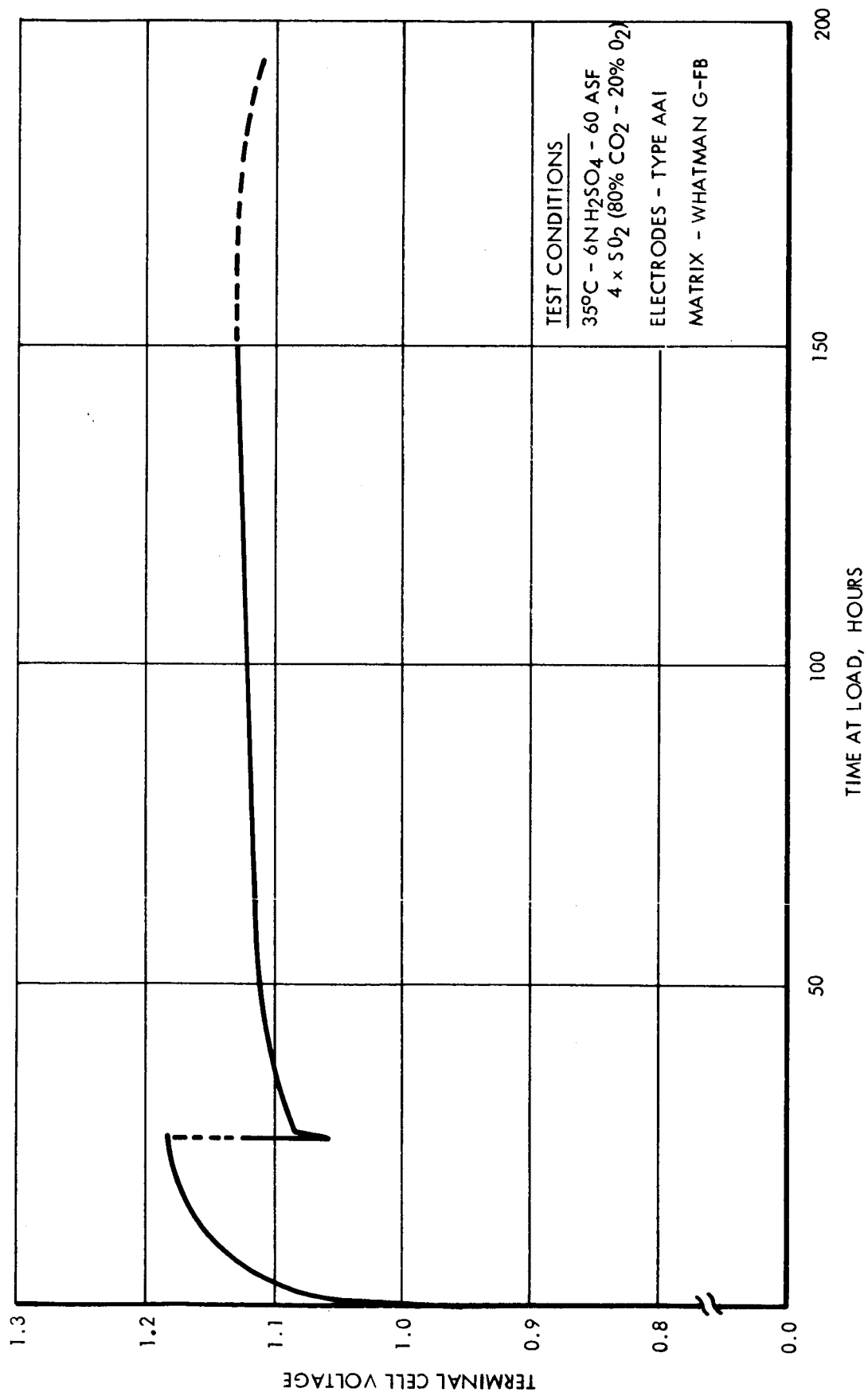


FIGURE 3-3 POLARIZATION TIME DEPENDENCE - STAGE III - TEST #M-2
(CELL TYPE MG/Ni/AU)

the end of the test the terminal voltage decreased. The test was terminated when some type of intermittent short between the cell plates occurred. This short was believed to be due to contamination in the cell constant temperature water bath.

Cell disassembly revealed a pinkish-red coloration on the cathode side of the matrix corresponding to the pin area. The cathode had a pinkish-red coloration on the pin contact side. No visible corrosion of the end plates was noted. By spectrographic analyses, the impurities on the electrodes and matrix were determined. The results of these analyses are presented in Table 3-2.

TABLE 3-2
SPECTROGRAPHIC ANALYSES OF ELECTRODES AND MATRIX
Samples Examined

<u>Elements Detected in %</u>	<u>Matrix Cathode Side</u>	<u>Matrix Anode Side</u>	<u>Cathode</u>	<u>Anode</u>	<u>Unused Matrix</u>
Au	AO.10	ND	0.8 to 1.0	ND	ND
Ni	0.01	0.01	0.01 to 0.10	0.01 to 0.10	ND
Cu	<0.01	<0.01	0.01 to 0.10	0.01 to 0.10	0.01
Zn	1.0 to 3.0	1.0 to 4.0	ND	ND	2.0 to 5.0
Mg	0.2 to 0.6	0.2 to 0.6	0.10 to 1.0	0.10 to 1.0	0.005 to 0.05

ND = Not Detected

A = Approximate

Results of the analyses indicate that the gold source is the cathode end plate. Gross corrosion products are not apparent. The magnesium detected may indicate a small crack in the plating, possibly in one of the gas ports which was somewhat scratched in the removal of a damaged plastic fitting.

It has been established that the Whatman GFB glass fiber paper used as the matrix will disintegrate with time when immersed in 30% sulphuric acid. Using a glass fiber matrix material with 5N H_2SO_4 at 70°C, a single cell life test on a fuel cell was conducted by American Cyanamid Company. Stable operation over a period of 1100 hours was observed, indicating that the glass fiber matrix does not cause cell performance degradation.

It is felt that the voltage increase with time noted in the small acid cell testing program is due to the use of the tantalum screen electrodes. Referring to the plastic cell results reported in Interim Report No. 1 and tests M-1 and M-2, the voltage increase obtained between one and eight hours at load is as follows:

<u>Test</u>	<u>ΔE (for 7 hours)</u>
Plastic Cell	90 mv
M-1	75 mv
M-2	82 mv (with O ₂ flow only)

It is seen that the same general increase is noted in each test, the common feature of each test was the type of electrode used, and the matrix material. Progressive oxidation of the tantalum screen appears to be a logical cause of the cell voltage increase with time.

3.4 Test in Progress

Additional testing using the gold plated magnesium cell is now being conducted. The cathode feed is the 80% CO₂ - 20% O₂ mixture. The start-up characteristic was similar to previous test runs. Complete test results are not available at this writing, but preliminary analysis indicates a terminal rate of voltage increase of approximately 0.025 mv/hr.

4.0 LARGE CELL PARAMETRIC TESTING

4.1 Stage I

The Stage I cell had to be assembled twice before a satisfactory seal was achieved both externally and internally. After all bolts are torqued in a set pattern, the cell is checked for external leaks with the cell dry internally. If seal is satisfactory, the electrolyte charging procedure is initiated. The entire cell cavity is put under a vacuum and then electrolyte is allowed to completely fill the void. Excess electrolyte is then drained from the cell, leaving only that electrolyte which wets the matrix. Gas pressure is then applied to one gas cavity with the other cavity being open to the atmosphere. The fully charged matrix, after the second assembly, successfully withstood a 16 psi pressure differential from anode to cathode cavity.

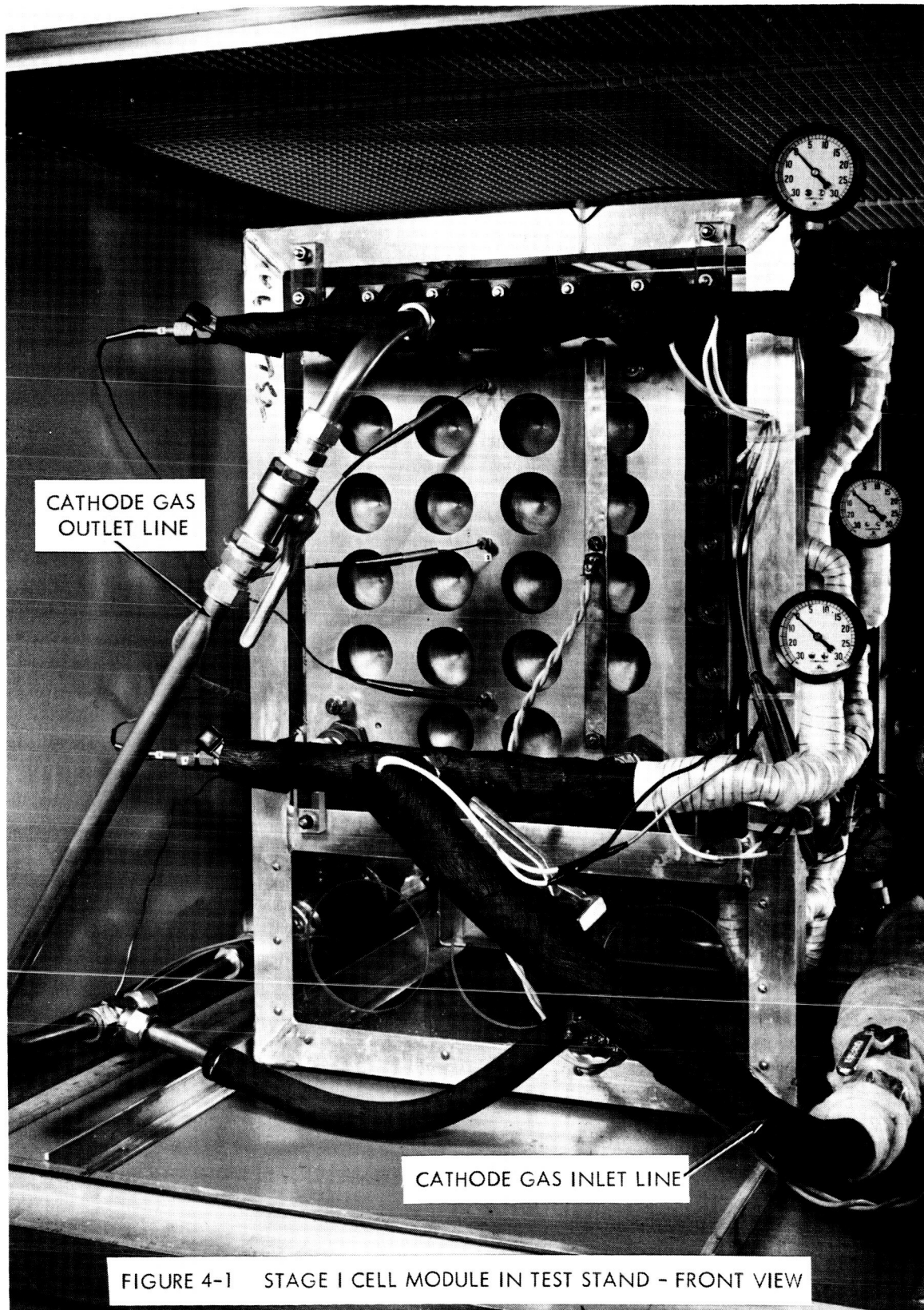
The fully charged cell was installed in the module rack and installed in the test stand. A check of air flow through the system and the Stage I cathode chamber was made. Pressure drops across the cathode cell field and across the entire cathode chamber (including inlet and outlet ports) checked with the calculated design values.

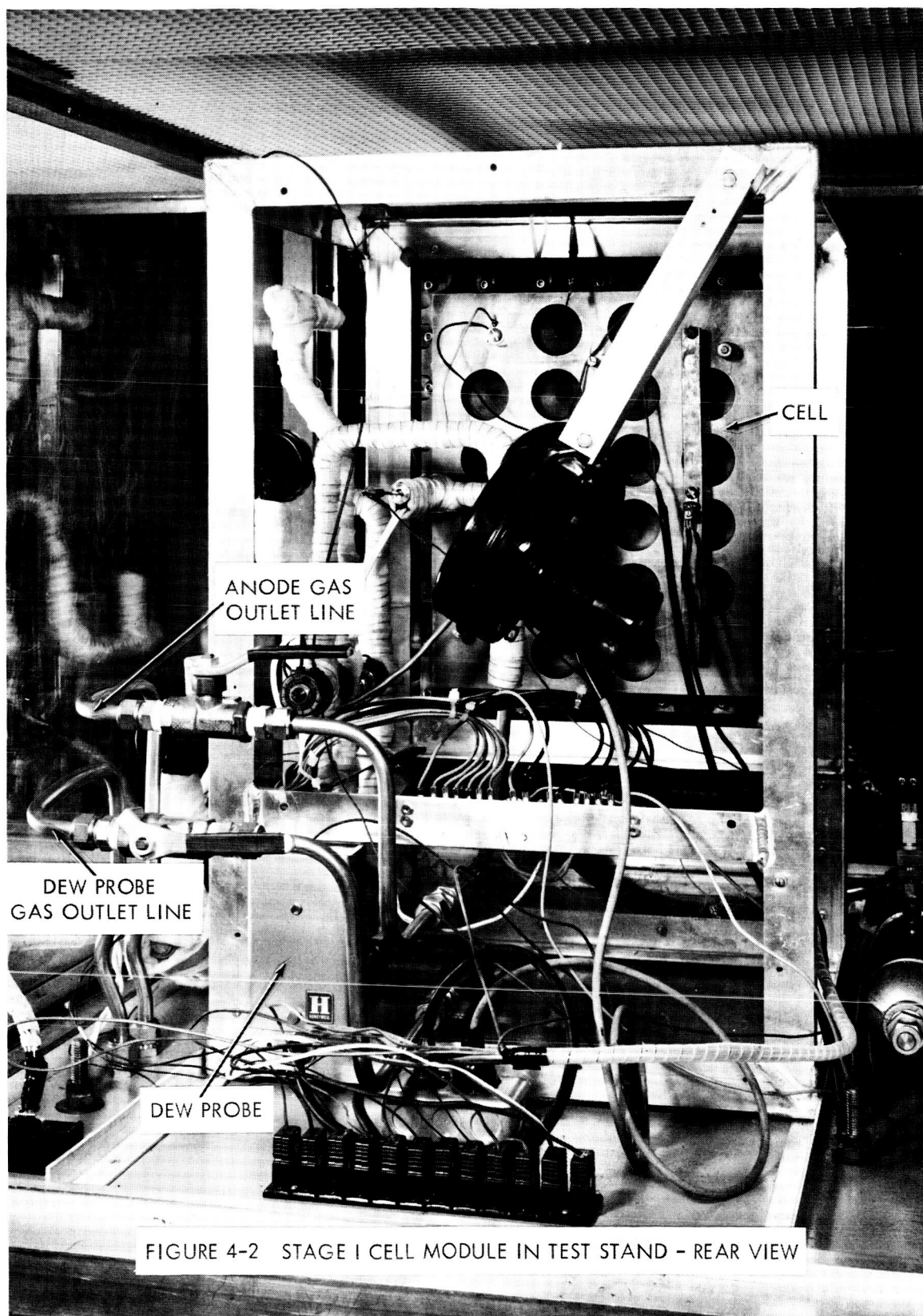
Figures 4-1 and 4-2 show the cell completely instrumented and installed in the test rig.

Several early test runs were terminated due to difficulties with the test rig. The difficulties and the corrective action were discussed in Section 2.0.

Normal test procedure followed during parametric testing was as follows:

1. With cell isolated from rest of system, heat the cell and humidifier to desired operating temperature.
2. Establish gas flow through humidifier while bypassing cell cathode chamber.





3. Establish proper gas composition.
4. Switch gas flow through the cathode chamber.
5. Turn on cell power.
6. Periodically determine gas composition of cathode inlet gas, cathode outlet gas, and anode gas measure anode gas flow rate.
7. Maintain operation for a four-hour period.
8. Cut off cell power.
9. Stop cathode gas flow.
10. Isolate cell cavity from rest of system to maintain proper cell water balance.
11. Repeat procedure for each desired cell operating point.

The direct current power supply used was not a constant current device, therefore some of the variations in cell performance were due to variations in the cell power applied.

4.1.1 Current Density Effects

Figure 4-3 presents the effect of cell current density on cell performance for three cell operating temperatures. The current, given in amperes, is the same value as the current density in amps/ft^2 , since the cell active electrode area is one square foot. At a cell temperature of 90°F the 30 ampere point was maintained for a short period (10 minutes) because of the high voltage. All the data points used are for a cathode gas flow rate based on twice the stoichiometric CO_2 requirement at a given cell operating current. It also should be noted that the electrolyte concentration was not identical for all runs due to the variations in make-up from batch to batch.

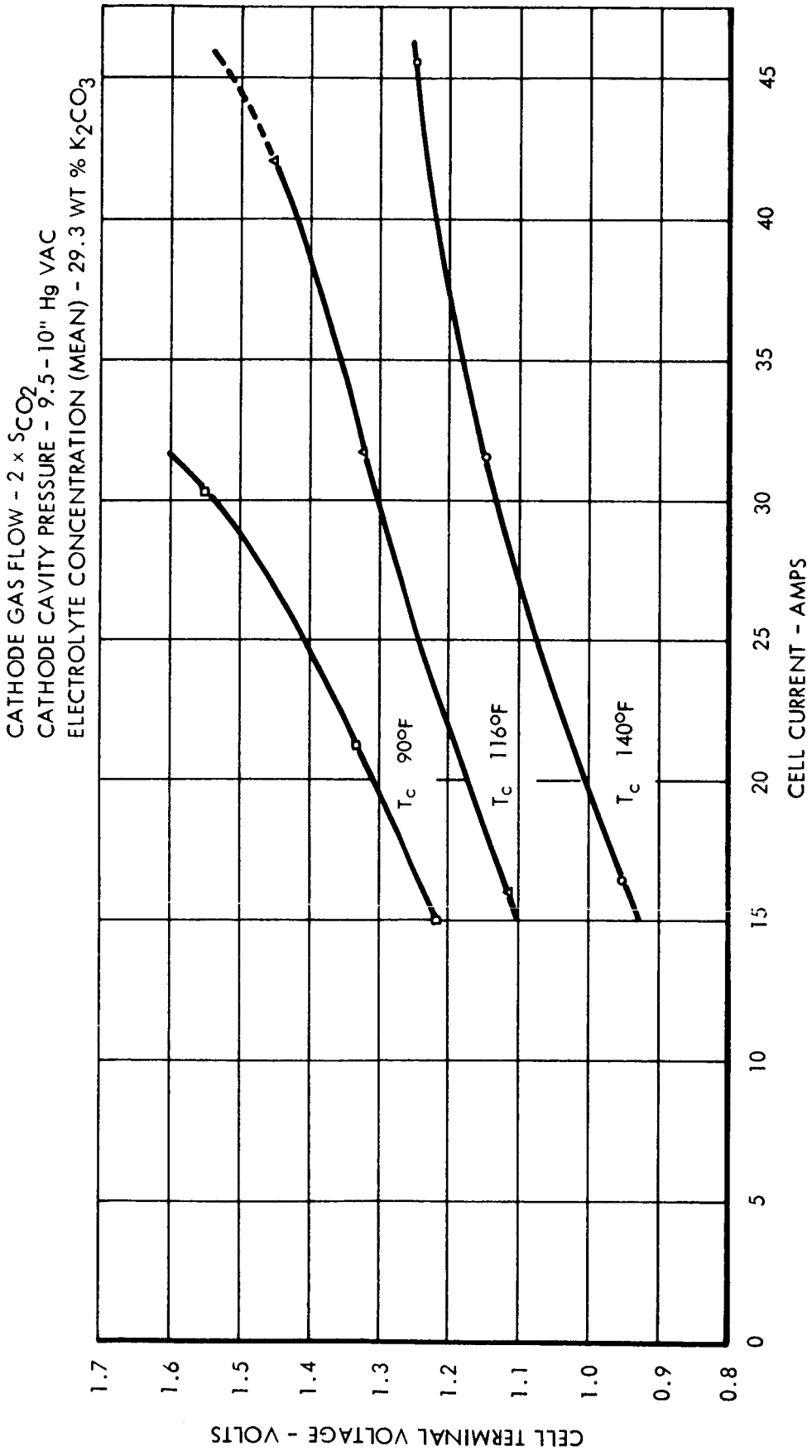


FIGURE 4-3 CELL VOLTAGE AS A FUNCTION OF CELL CURRENT

4.1.2 Cell Temperature Effect

Figure 4-4 is a cross-plot obtained from Figure 4-3, showing the strong effect cell temperature has on cell current density for a given voltage. Similar curves for the voltage as a function of cell temperature at a constant current can be drawn using the data from Figure 4-3.

4.1.3 Cathode Gas Flow Rate Effects

The cathode gas flow was normally maintained at twice stoichiometric CO_2 with one run at a $5 \times S_{\text{CO}_2}$ flow. There were however two runs made at a cathode flow of $1 \times S_{\text{CO}_2}$, made when the cell current was increased from 15 amps to 30 amps prior to increasing the cathode gas flow to match the higher current. Using the data obtained at these additional flow ratios, Figure 4-5 was plotted to show the effect of the stoichiometric flow ratio on cell voltage and per cent of CO_2 in the anode gas output. At the very low ratios, cell electrical performance improves at the expense of the per cent CO_2 transferred across the cell. The change in cell voltage at the low flow ratio may be due to a change in electrolyte composition as the average CO_2 partial pressure in the cathode cavity falls below a certain critical value as CO_2 is scrubbed from the air by the electrolyte.

4.1.4 Carbon Dioxide Transfer

The percent of CO_2 in the anode gas and the CO_2 transfer rate as a function of cell current density are given in Figure 4-6 for the three cell temperatures. The apparent increase of the CO_2 transfer rate with current density between 15 and 30 ASF at 140°F is not statistically significant. The observed CO_2 transfer rate at 30 ASF has a deviation from the arithmetic mean which was twice as great as all other observations in this test series. However it should be noted that the effect of increasing the current density at all temperatures was to significantly depress the CO_2 transfer rate.

4.1.5 Polarization Time Dependence

Figures 4-7 through 4-15 give the polarization time dependence for the required test conditions. Comments concerning some of the runs are given below. Where no comments for a run are given, no further data, other than that on

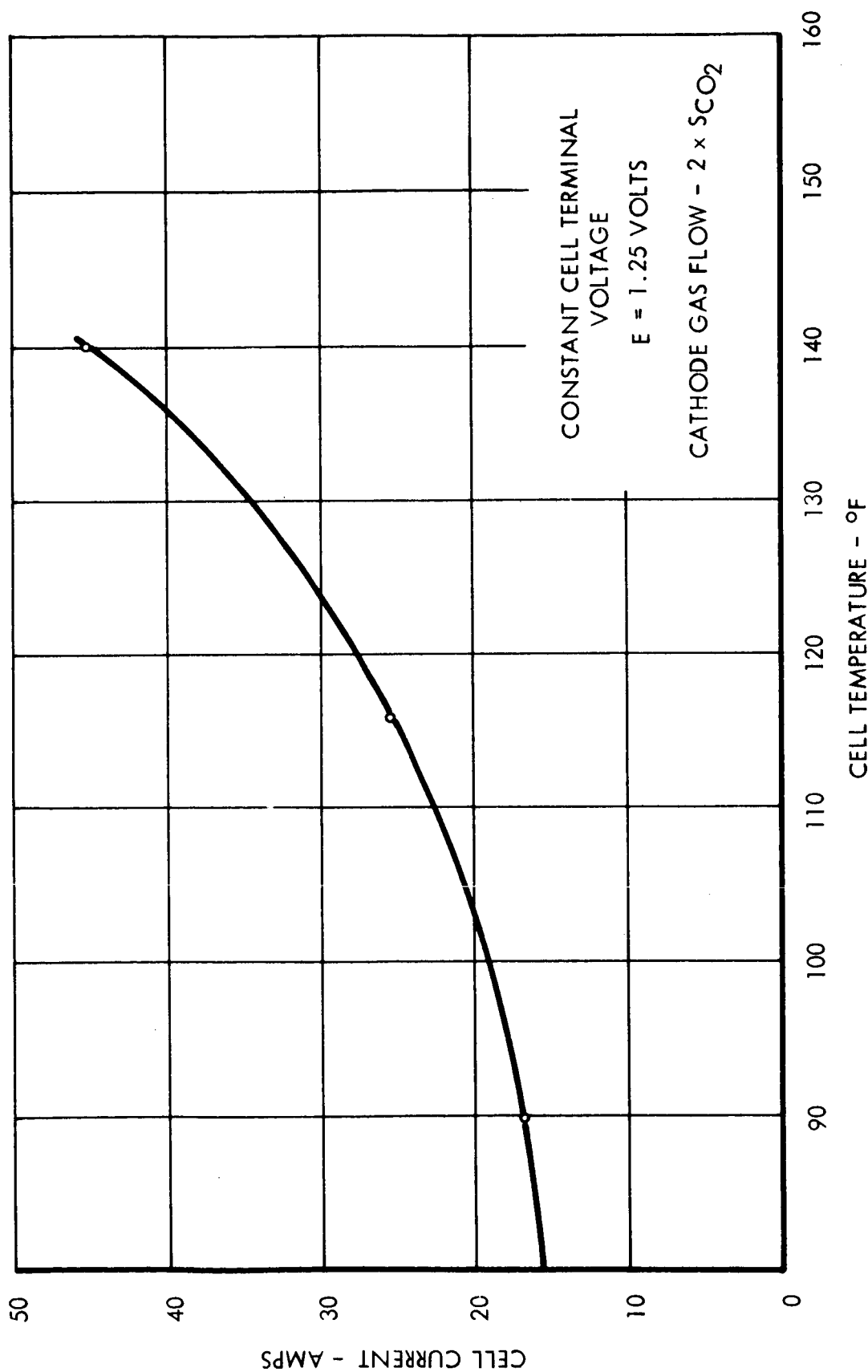


FIGURE 4-4 STAGE I CELL CURRENT AS A FUNCTION OF CELL TEMPERATURE

- Δ $T_c = 116^\circ\text{F}$, $I = 31.5$ AMPS
 \circ $T_c = 140^\circ\text{F}$, $I = 30.5$ AMPS

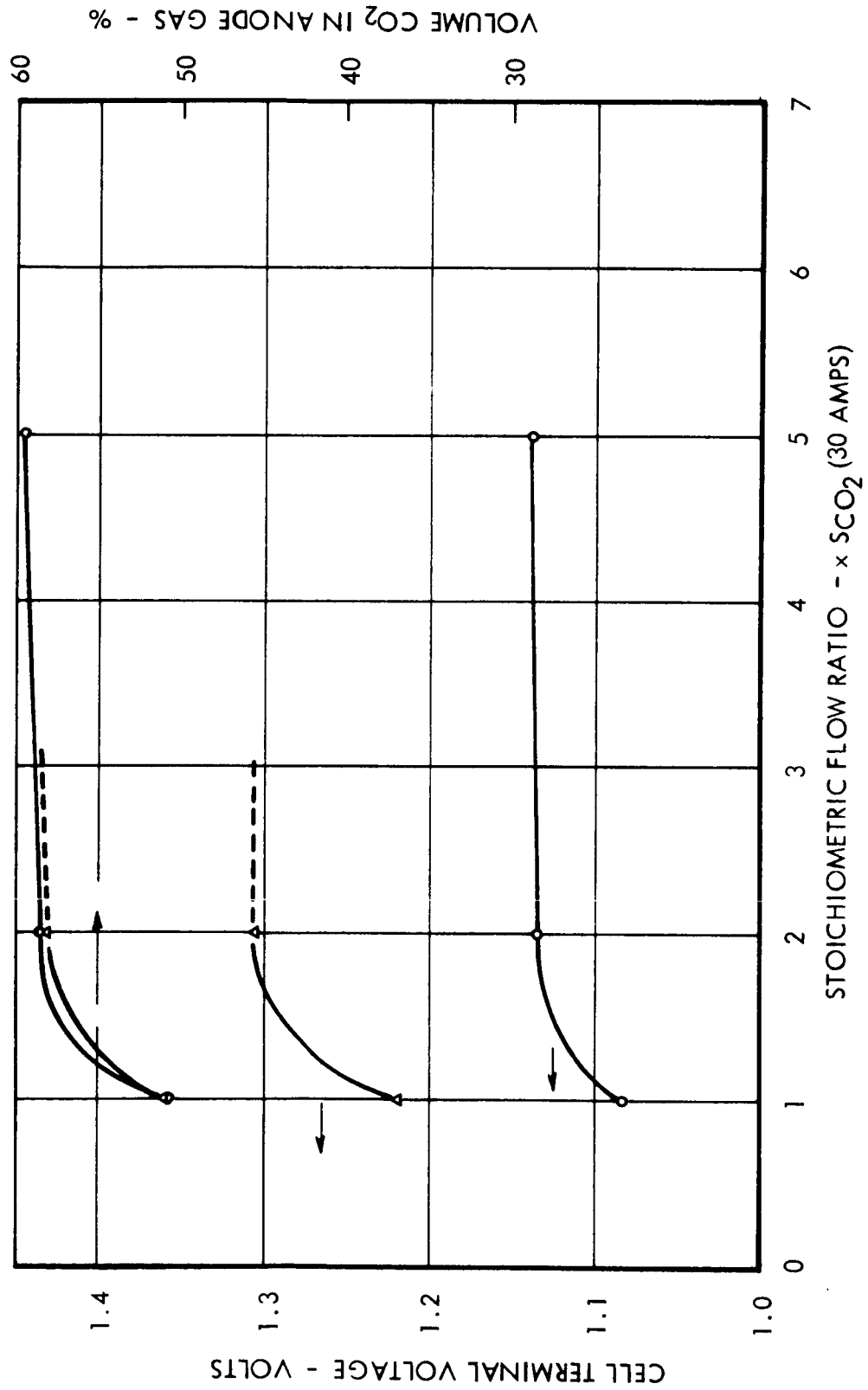


FIGURE 4-5 CELL PERFORMANCE AS A FUNCTION OF CATHODE GAS FLOW RATE

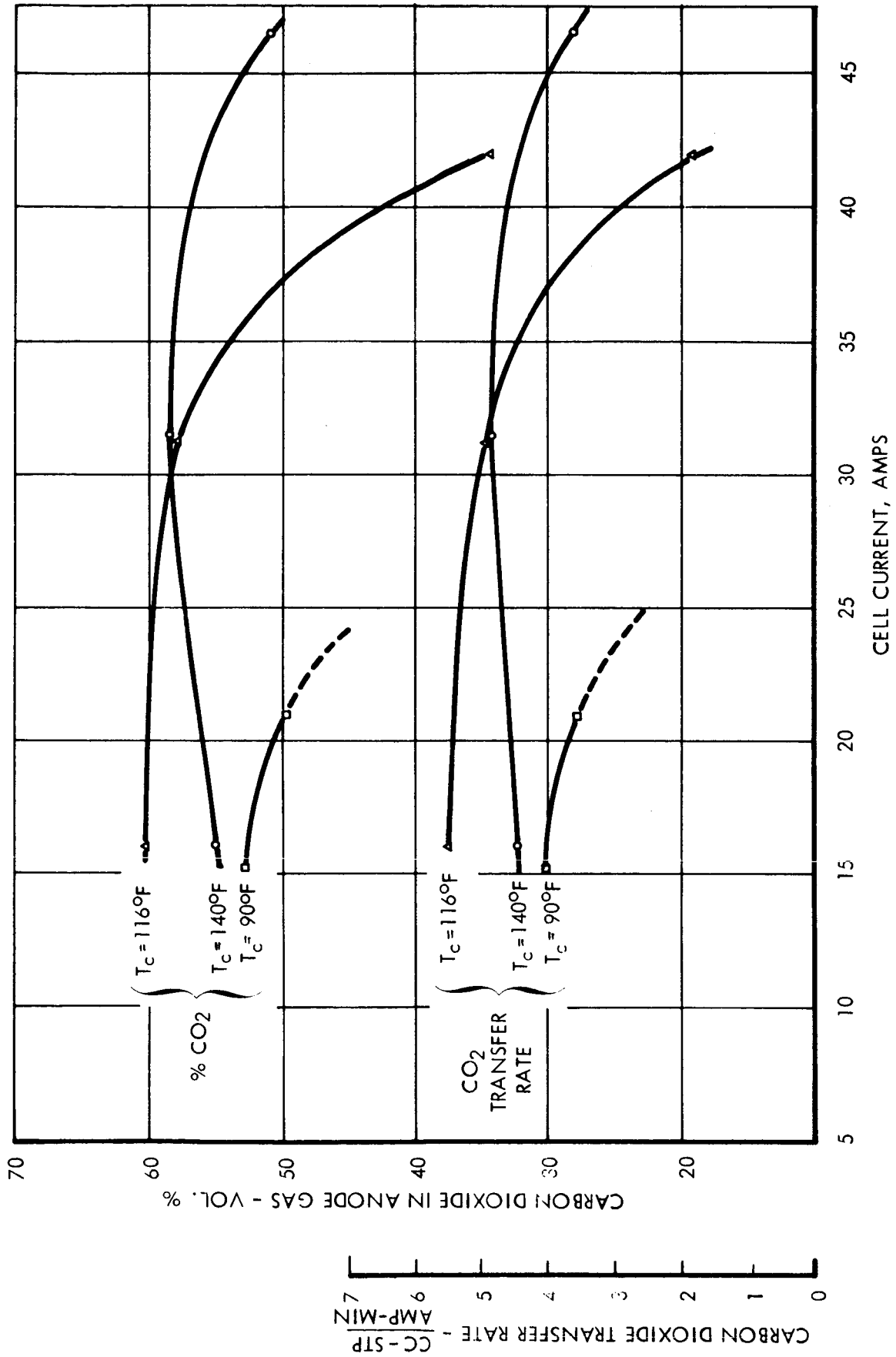


FIGURE 4-6 CARBON DIOXIDE TRANSFER AS A FUNCTION OF CELL CURRENT

the graph, is readily available to explain odd shapes in the polarization curves. As stated, the cell current in amperes is equivalent to the cell current density in amps/ft².

1. Figure 4-7. This was the first operating condition after the test rig modifications were completed. An overnight run was completed to check the rig for proper operation, resulting in a test run just short of 24 hours in duration.
2. Figure 4-8. The cell current was decreased at $t = 206$ minutes to bring the current closer to the 30 ampere nominal operating point.
3. Figure 4-11. As indicated on the graph, adjustments in the cathode gas flow were made early in the run after the power to the cell had been turned on. The steady rise in cell voltage is due to the steady increase in the cell current density. At $t = 200$ minutes the power relay controlling the humidifier heater stuck in the on position. A rapid increase in the cell temperature and inlet gas dew point temperature caused a rapid decrease in cell voltage and increase in cell current. The high dew point of the incoming gas (200°F) then rapidly flooded the cell causing complete deterioration in cell performance.
4. Figure 4-12. The large voltage fluctuations are due primarily to the wide cell temperature changes. Control of the cell temperature became difficult at the high power input level at this low operating temperature (115°F). Nearing the end of the run, the cell stabilized as better temperature control of the cell was achieved.
5. Figure 4-14. After twelve minutes of operation, cell current was decreased from 30 amps to 21 amps without change in gas flow. Fluctuating cell temperature and inlet gas dew point temperature caused erratic operation. At $t = 184$ minutes,

CELL CURRENT ~ 15 AMPS
 CELL TEMPERATURE - 140°F
 CATHODE GAS INLET DEW POINT - 133°F
 CATHODE CAVITY PRESSURE - 9.5 - 10" Hg VAC
 CATHODE GAS FLOW - $2 \times 5 \text{ CO}_2$ (15 AMPS)
 ELECTROLYTE CONCENTRATION - 28.4 WT % K_2CO_3
 T_c RANGE - 138.5 - 140.5°F
 T_{DP} RANGE - 132 - 133.5°F

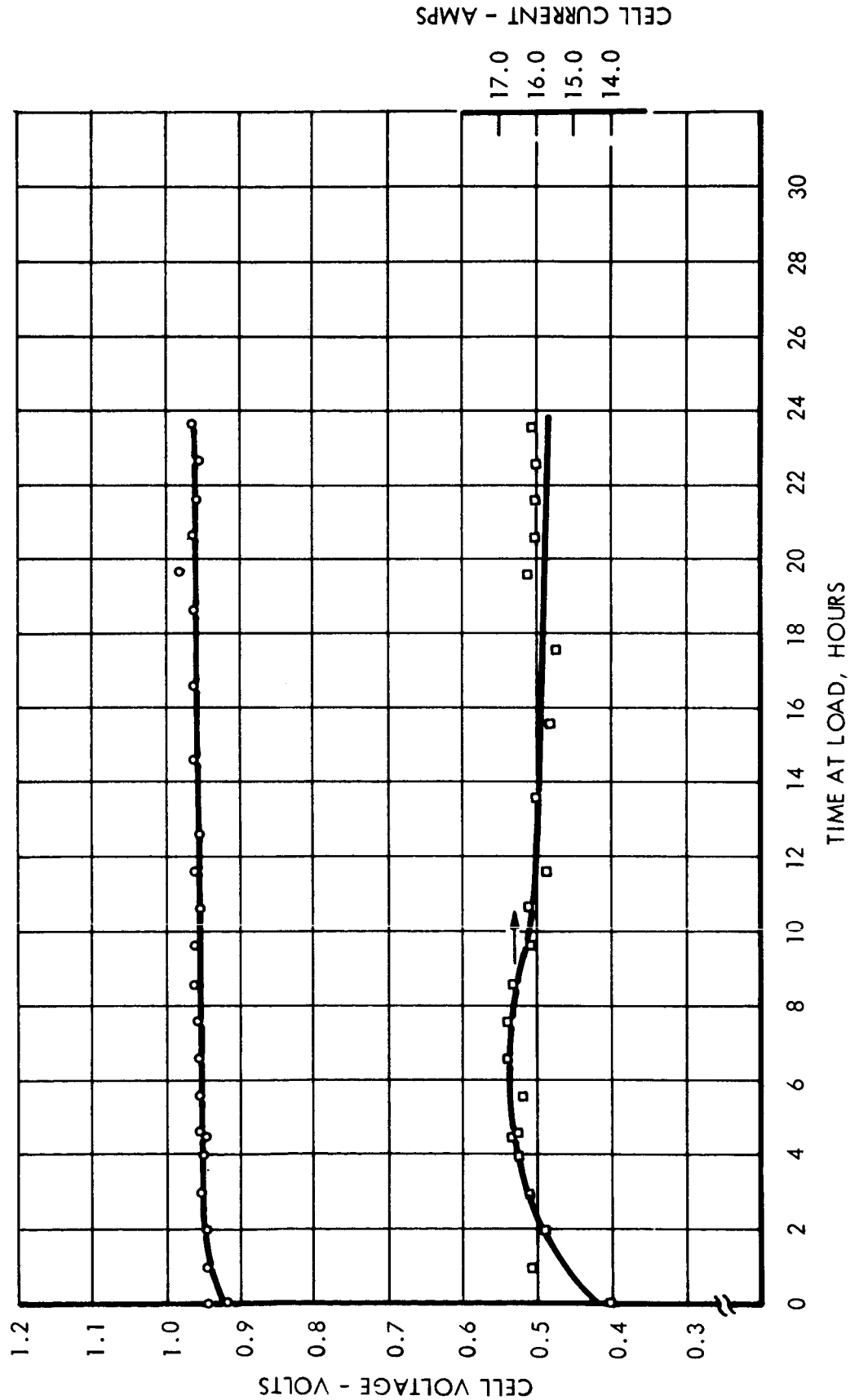


FIGURE 4-7 STAGE I CELL - POLARIZATION TIME DEPENDENCE, $T = 140^\circ\text{F}$, $I = 15$

CELL CURRENT ~ 30 AMPS
 CELL TEMPERATURE - 140°F
 CATHODE GAS INLET DEW POINT - 133°F
 CATHODE CAVITY PRESSURE - 9.5 - 10" Hg-VAC
 CATHODE GAS FLOW - $2 \times S_{CO_2}$ (30 AMPS)
 ELECTROLYTE CONCENTRATION - 28.4 WT % K_2CO_3
 T_c RANGE - 140.5°F - 142°F
 T_{DP} RANGE - 133.75°F - 133.75°F → INC. WITH TIME

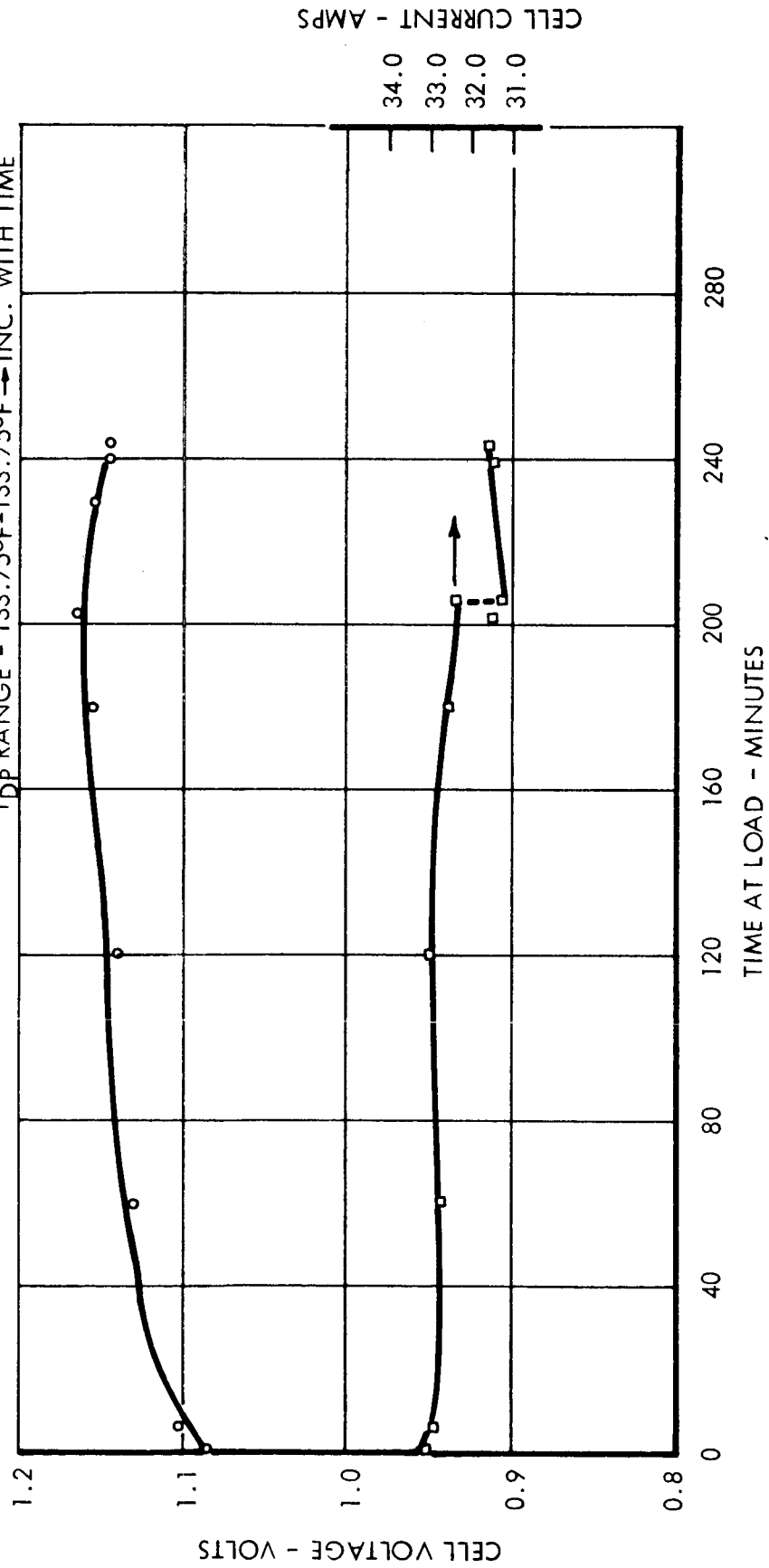


FIGURE 4-8 STAGE I CELL - POLARIZATION TIME DEPENDENCE, $T = 140^\circ F$, $I = 30$

CELL CURRENT ~45 AMPS
 CELL TEMPERATURE - 140°F
 CATHODE GAS INLET DEW POINT - 133°F
 CATHODE CAVITY PRESSURE - 9.5-10" Hg-VAC
 CATHODE GAS FLOW - 2 x 5CO₂ (45 AMPS)
 ELECTROLYTE CONCENTRATION - 28.4 WT % K₂CO₃
 T_C RANGE - 138.5 → 143.0°F
 T_{DP} RANGE - 133 - 133.5°F

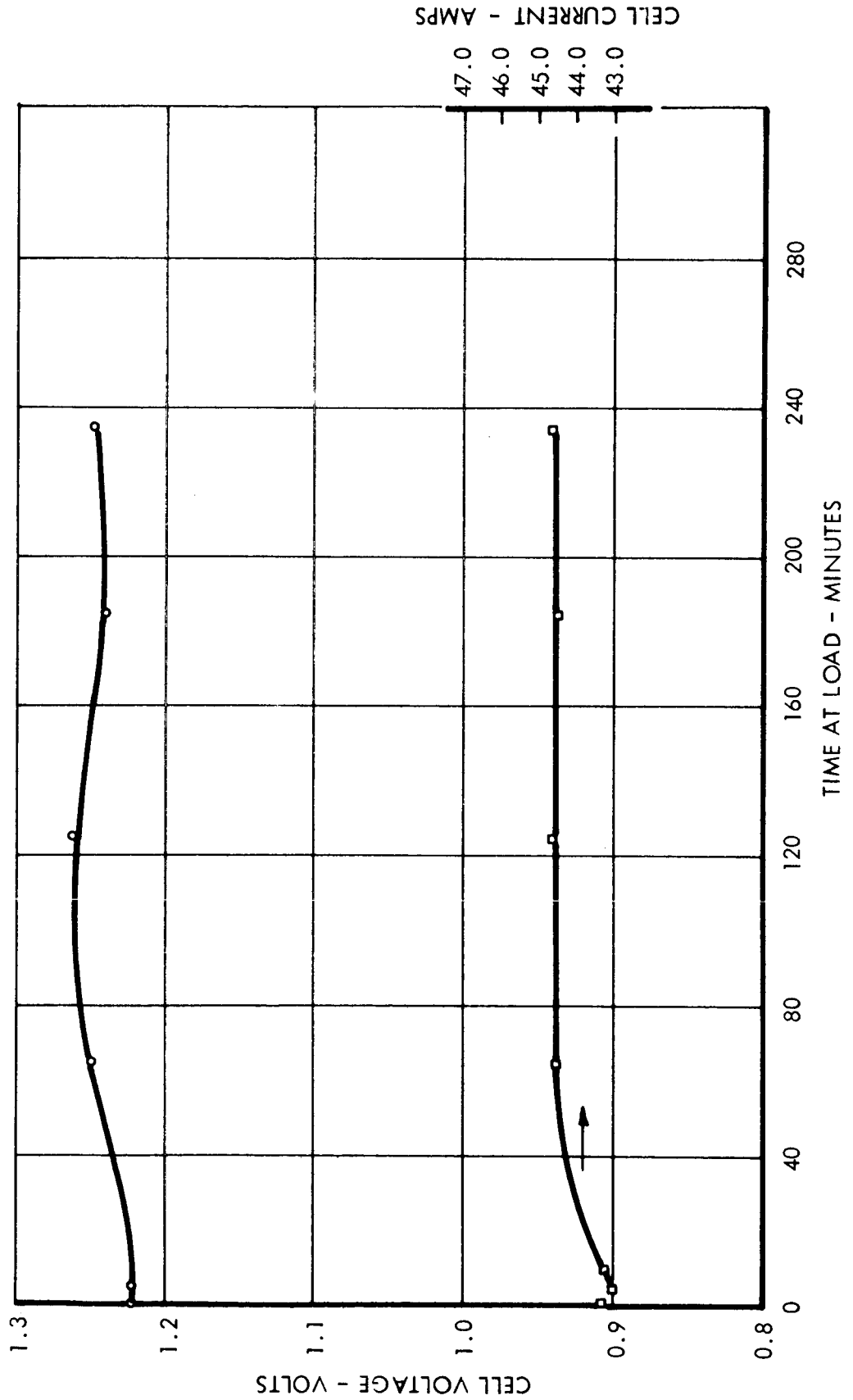


FIGURE 4-9 STAGE I CELL - POLARIZATION TIME DEPENDENCE, T = 140°F, I = 45

CELL CURRENT ~ 15 AMPS
 CELL TEMPERATURE - 115°F
 CATHODE GAS INLET DEW POINT - 110°F
 CATHODE CAVITY PRESSURE - 9.5-10" Hg-VAC
 CATHODE GAS FLOW - 2 x SCO_2 (15 AMPS)
 ELECTROLYTE CONCENTRATION - 28.4 WT % K_2CO_3
 T_c RANGE - 115 - 117.5°F
 T_{DP} RANGE - 109.5 - 111.0°F

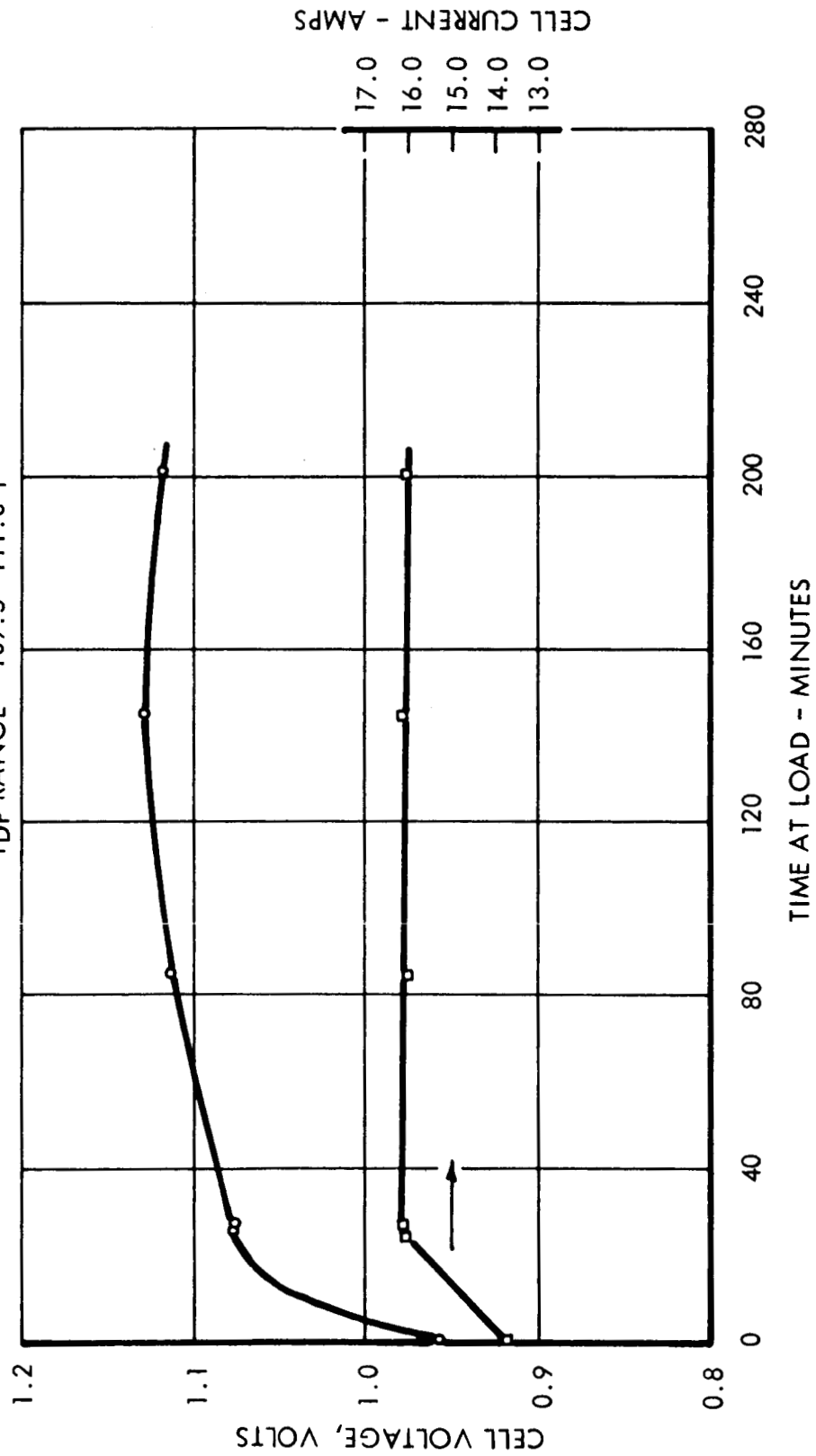


FIGURE 4-10 STAGE I CELL - POLARIZATION TIME DEPENDENCE, $T = 115^\circ\text{F}$, $I = 15$

CELL CURRENT ~ 30 AMPS
 CELL TEMPERATURE - 115°F
 CATHODE GAS INLET DEW POINT - 110°F
 CATHODE CAVITY PRESSURE - 9.5-10" Hg VAC
 CATHODE GAS FLOW - 2 x SCO₂ (30 AMPS)
 ELECTROLYTE CONCENTRATION - 28.4 WT K₂CO₃
 T_c RANGE - 117 - 118°F (UNTIL FAILURE)
 T_{DP} RANGE - 110 - 111.5°F (UNTIL FAILURE)

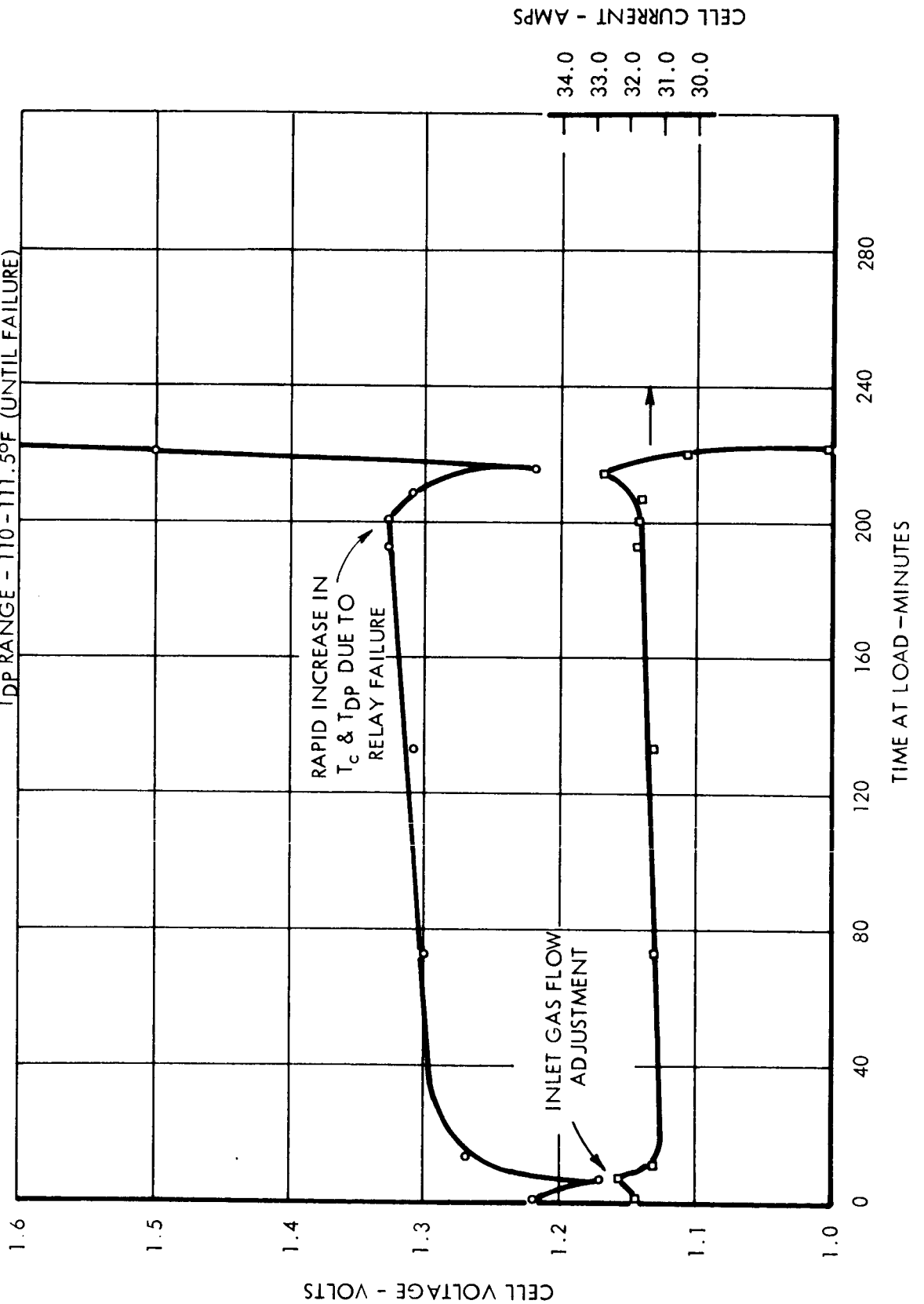


FIGURE 4-11 STAGE I CELL - POLARIZATION TIME DEPENDENCE, T = 115°F, I = 30

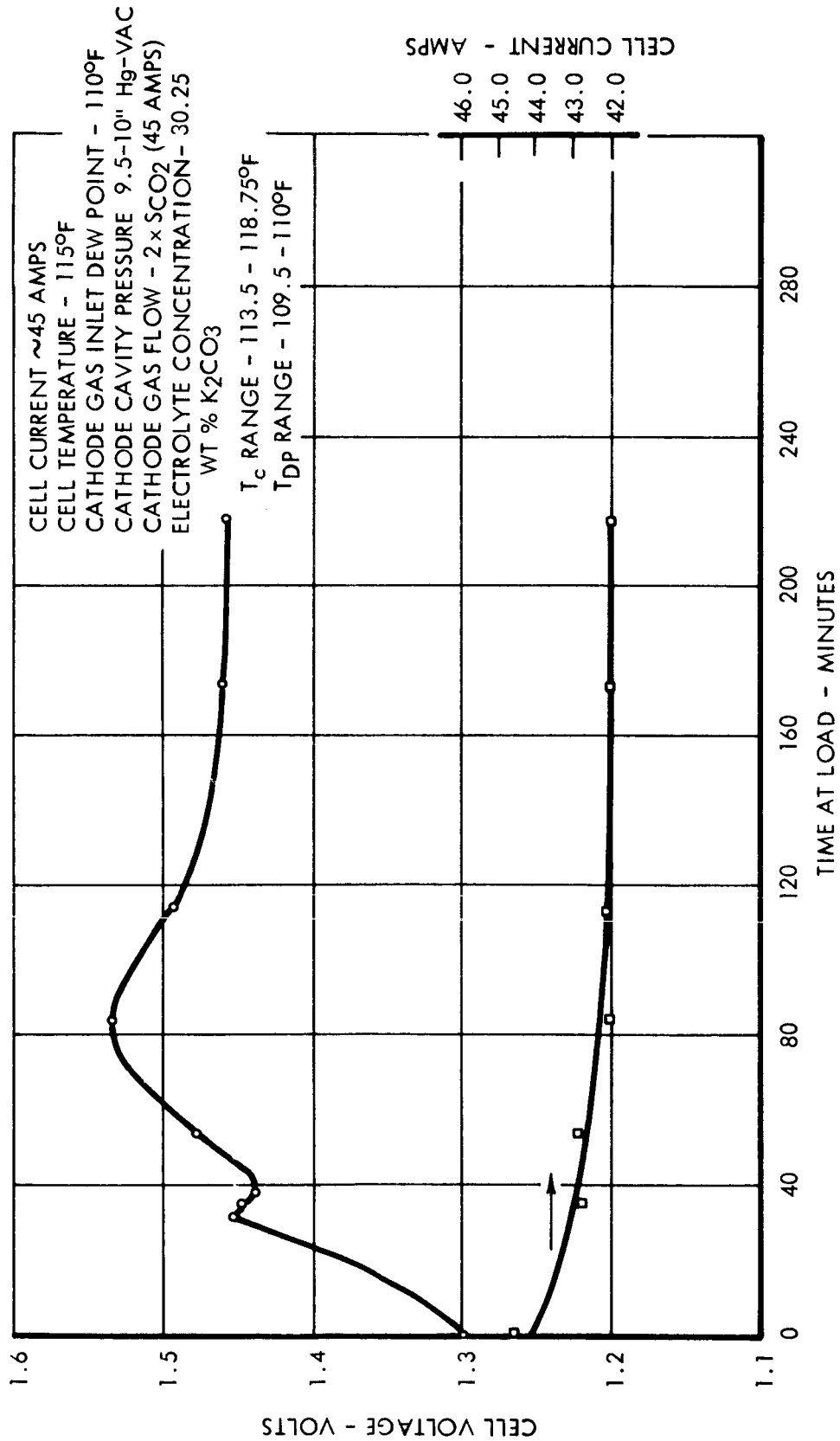


FIGURE 4-12 STAGE I CELL - POLARIZATION TIME DEPENDENCE, $T=115^\circ\text{F}$, $I=45$

CELL CURRENT ~ 15 AMPS
 CELL TEMPERATURE - 90°F
 CATHODE GAS INLET DEW POINT - 84°F
 CATHODE CAVITY PRESSURE - 9.5-10" Hg VAC
 CATHODE GAS FLOW - $2 \times 5\text{CO}_2$ (15 AMPS)
 ELECTROLYTE CONCENTRATION - 36.25% K_2CO_3
 T_c RANGE - 89.5-91°F
 T_{DP} RANGE - 83-85.5°F

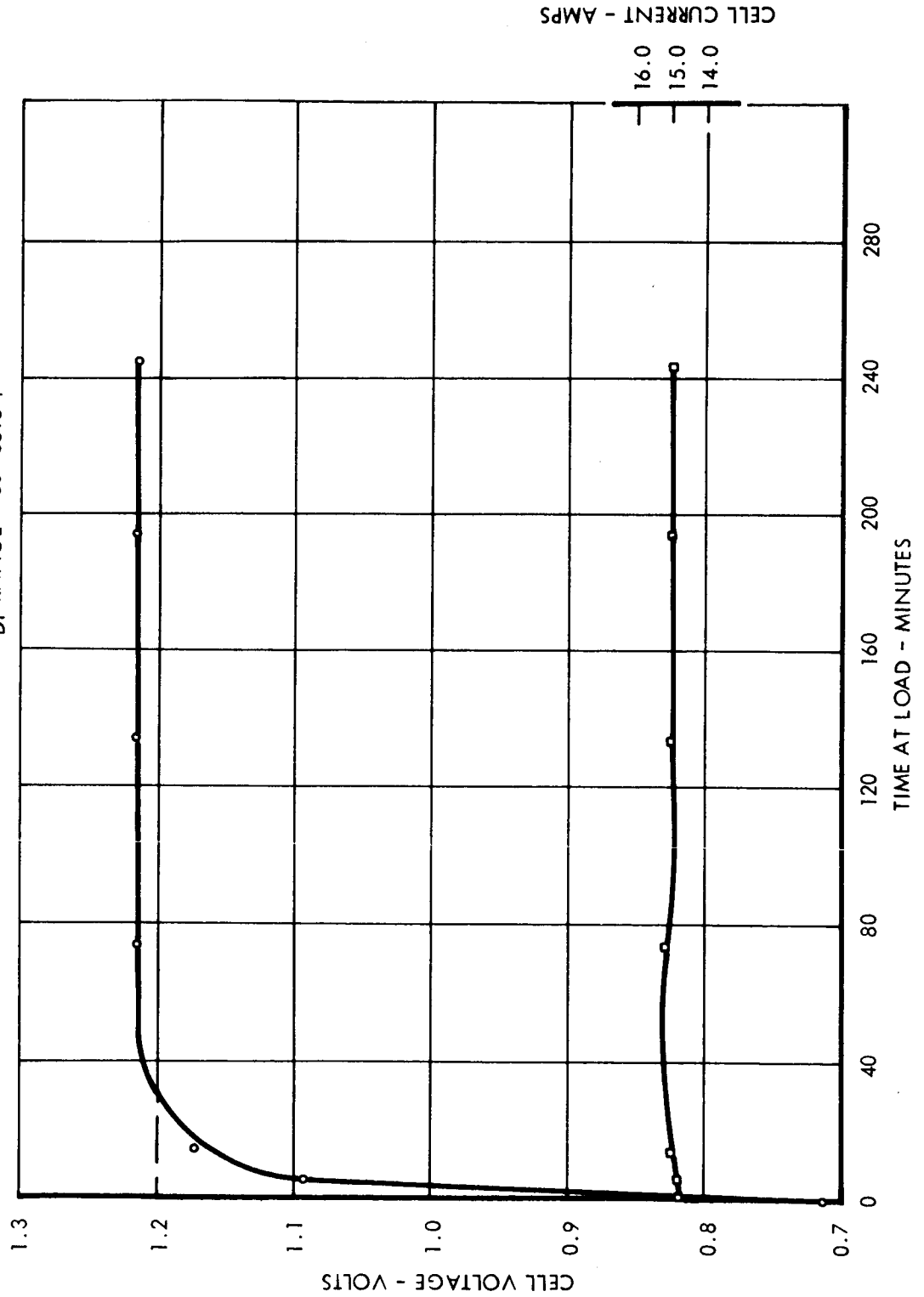


FIGURE 4-13 STAGE I CELL - POLARIZATION TIME DEPENDENCE, $T = 90^\circ\text{F}$, $I = 15$

CELL TEMPERATURE ~ 90°F
 CATHODE GAS INLET DEW POINT - 84°F
 CATHODE CAVITY PRESSURE - 9.5-10" Hg VAC
 CATHODE GAS FLOW (a) $2 \times \text{SCO}_2$ (30 AMPS)
 (b) $2 \times \text{SCO}_2$ (20 AMPS)
 ELECTROLYTE CONCENTRATION - 32.25 WT % K_2CO_3
 T_c RANGE - 90-93.25°F
 T_{DP} RANGE - 83.5-88.5°F

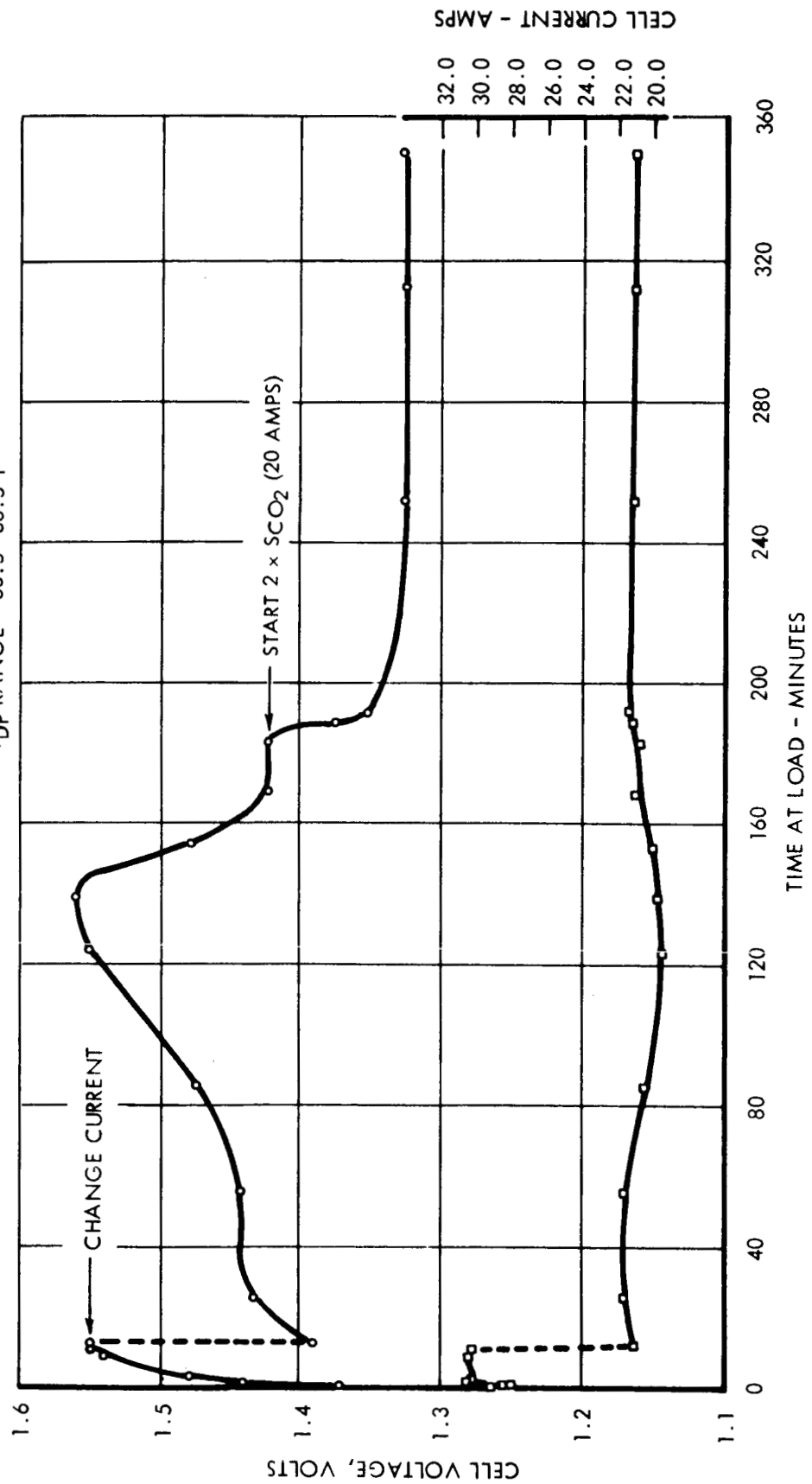


FIGURE 4-14 STAGE I CELL - POLARIZATION TIME DEPENDENCE, $T \approx 90^\circ\text{F}$, I (20-30)

the cathode gas flow was adjusted to $2 \times S_{CO_2}$ for the 20 amp operating level. Stable performance was achieved as proper humidifier and cell temperatures were established.

6. Figure 4-15. This run was at the $5 \times S$ flow ratio. Again it is seen that the cell temperature ($136 - 143^{\circ}\text{F}$) and inlet gas dew point temperature ($131.5 - 134.5^{\circ}\text{F}$) varied over a considerable range contributing to variable cell performance. The cell current was adjusted at $t = 212$ minutes and $t = 237$ minutes.

4.2 Stage II

The assembly of the Stage II cell was more complex than the Stage I cell due to the recessed liquid cavity and gas diffusion plate. A gas-tight seal was established between the recessed cavity and the gas diffusion plate while maintaining electrical continuity. To eliminate unnecessary errors in measuring the cell potential, a wire was attached directly to the gas diffusion plate and passed out of the cell through one of the gas manifold outlets. Use of this wire by-passed the problems associated with connecting directly to the cathode end plate. The other lead for potential measurement was attached directly to the anode end plate since this end plate contacts the anode directly.

Figures 4-16 and 4-17 show the Stage II cell components during assembly. Note the fiberglass strip inserts in the pin structure of the gas diffusion plate. This provides the gas flow pattern through the cathode chamber. A tantalum screen is attached to the cathode end plate and another to one side of the gas diffusion plate. These screens will contain the asbestos matrix used to seal off the liquid reservoir. The platinum cathode is attached directly to the other side of the gas diffusion plate.

Electrolyte charging of the cell was the same as with Stage I. The cell was checked for internal sealing from cathode chamber to anode chamber and from cathode to liquid reservoir chamber. Upon establishment of a proper seal the cell was installed in the module and the test rig.

CELL CURRENT ~ 30 AMPS
 CELL TEMPERATURE - 140°F
 CATHODE GAS INLET DEW POINT - 133°F
 CATHODE CAVITY PRESSURE - 9.5-10" Hg VAC
 CATHODE GAS FLOW - 5 x SCO_2 (30 AMPS)
 ELECTROLYTE CONCENTRATION - 31 WT % K_2CO_3
 T_c RANGE - 136-143°F
 T_{DP} RANGE - 131.5-134.5°F

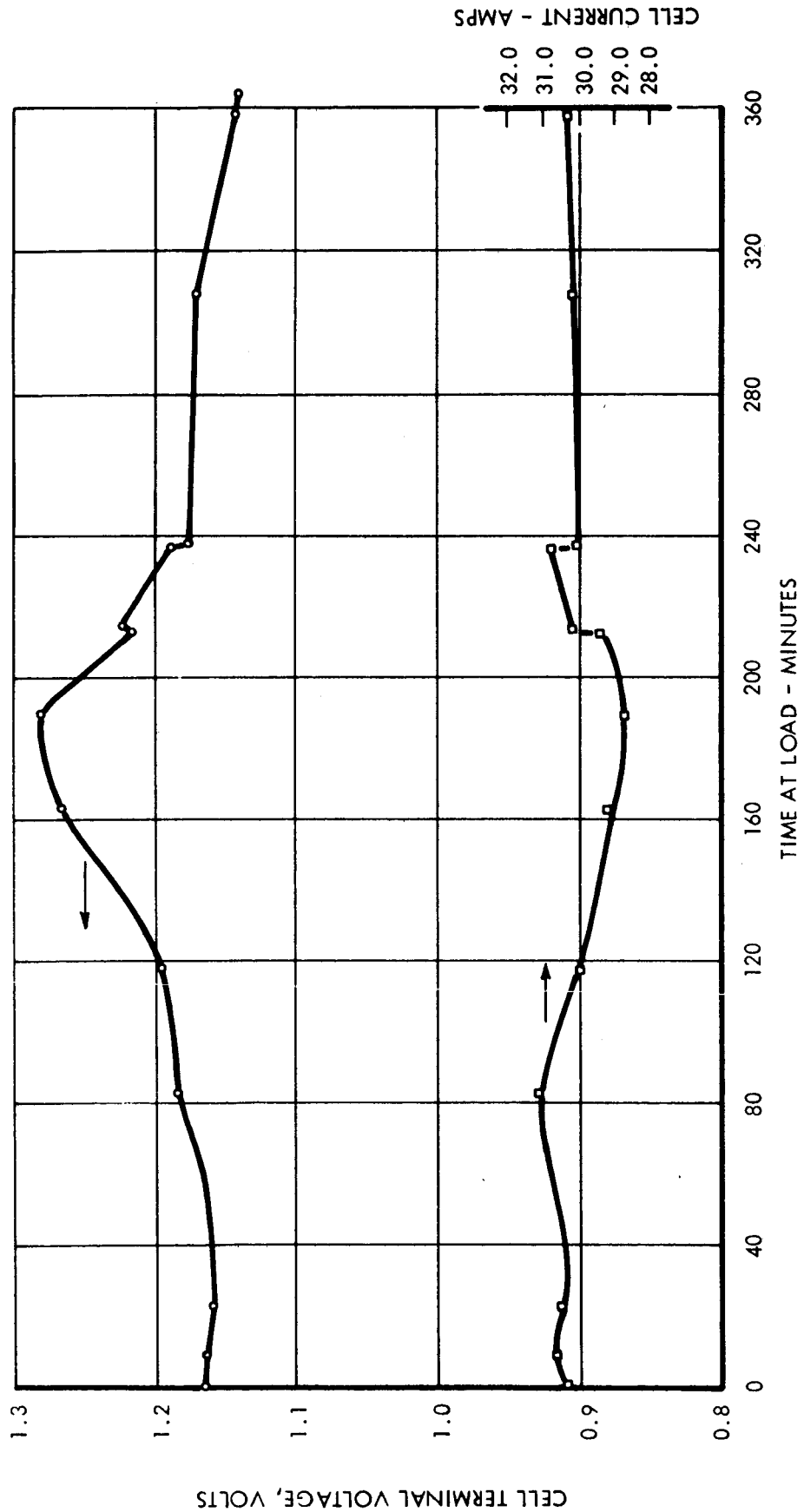


FIGURE 4-15 STAGE I CELL - POLARIZATION TIME DEPENDENCE, $T = 140^\circ\text{F}$, $I = 30$,
 5 x 5 FLOW

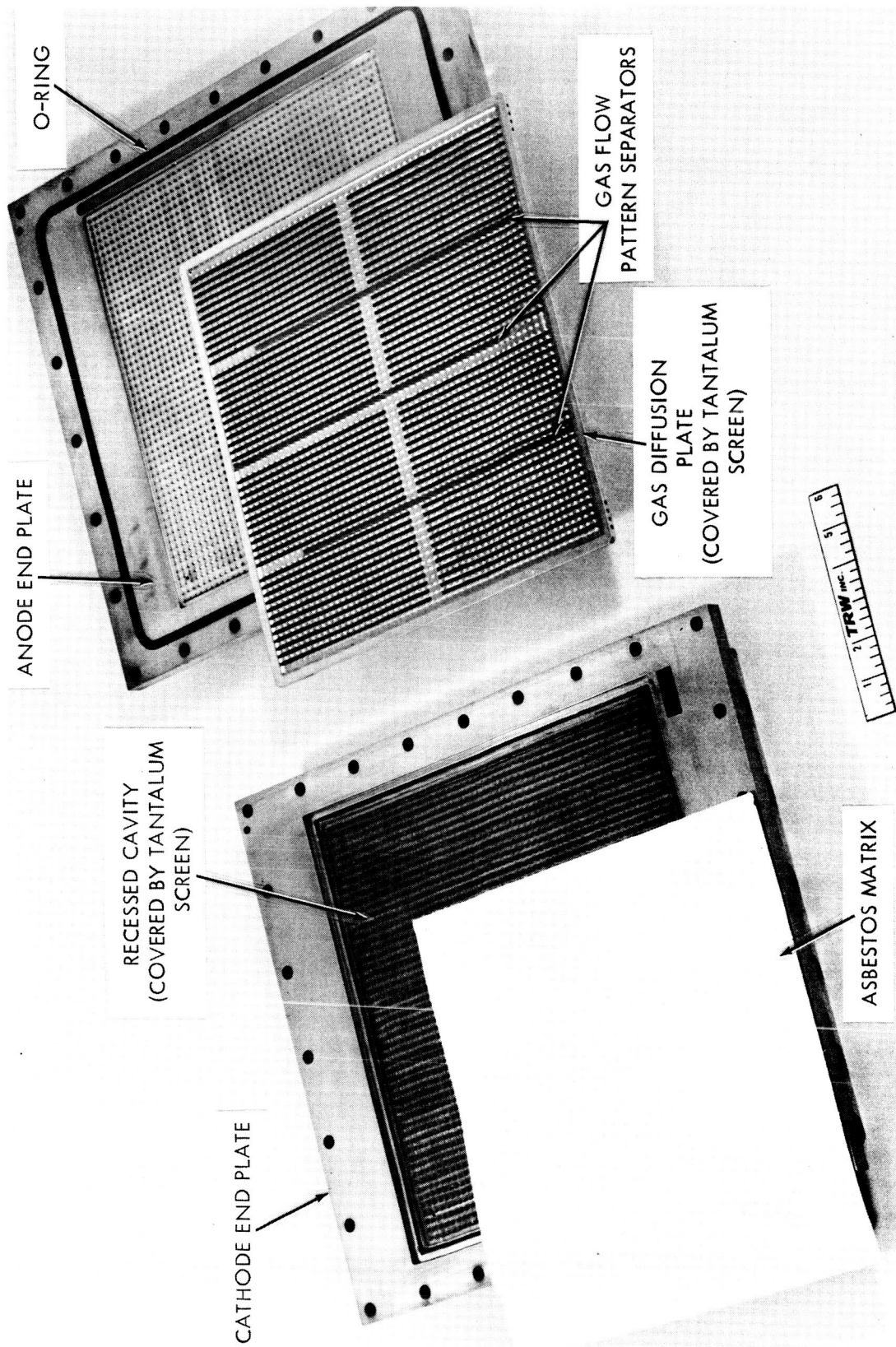


FIGURE 4-16 STAGE II CELL - PARTIALLY ASSEMBLED - LIQUID SIDE OF GAS DIFFUSION PLATE

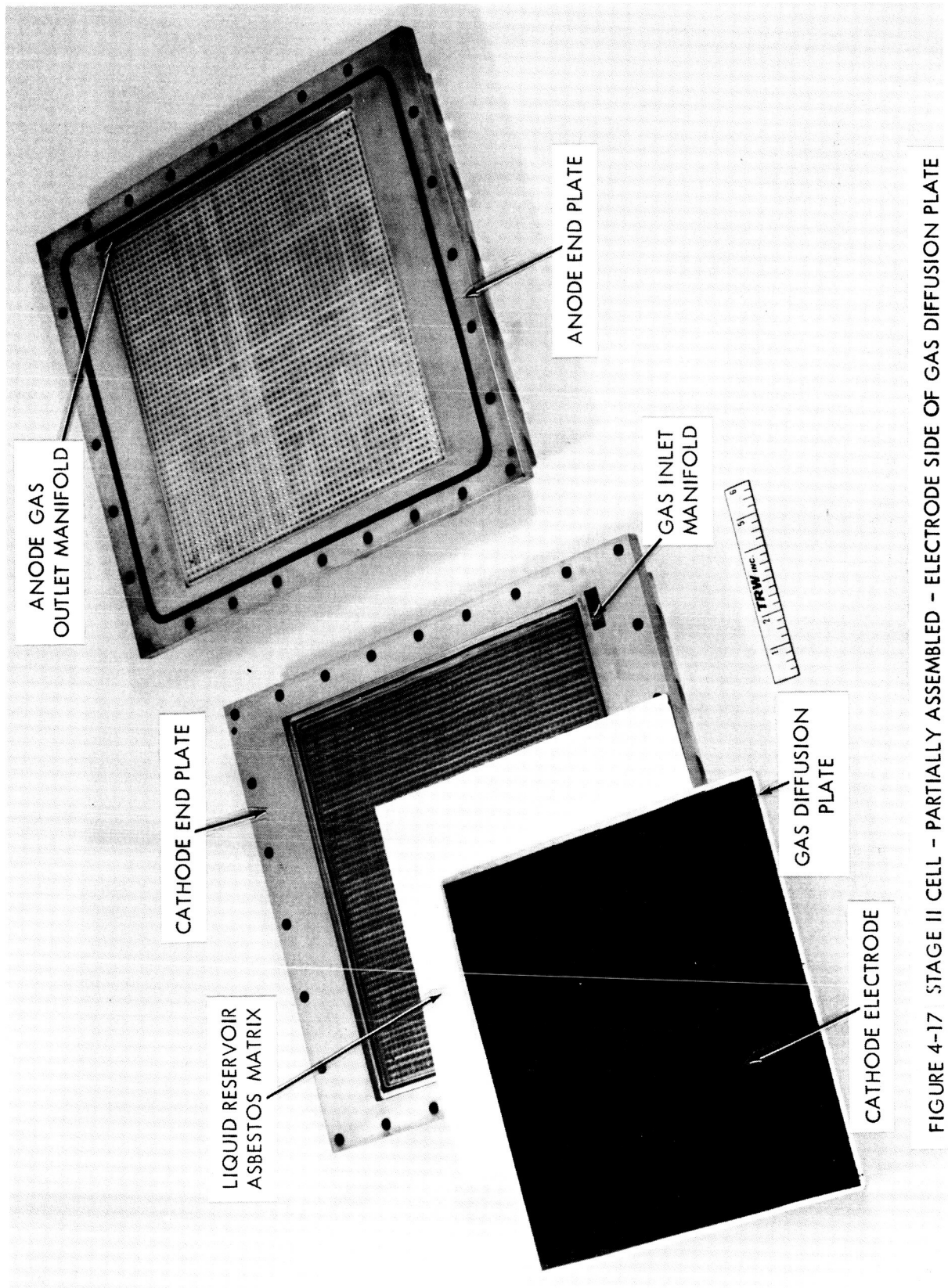


FIGURE 4-17 STAGE II CELL - PARTIALLY ASSEMBLED - ELECTRODE SIDE OF GAS DIFFUSION PLATE

At this writing, the Stage II cell is being tested at 176°F and 122°F at current densities of 15, 30, and 45 ASF. Preliminary results indicate satisfactory operation.

4.3 Stage III

Major components for a Stage III acid cell are shown in Figure 4-18. The actual configuration of the pin structure is identical to Stage II except for the inclusion of the gold current collectors. Assembly of the cell is now in progress.

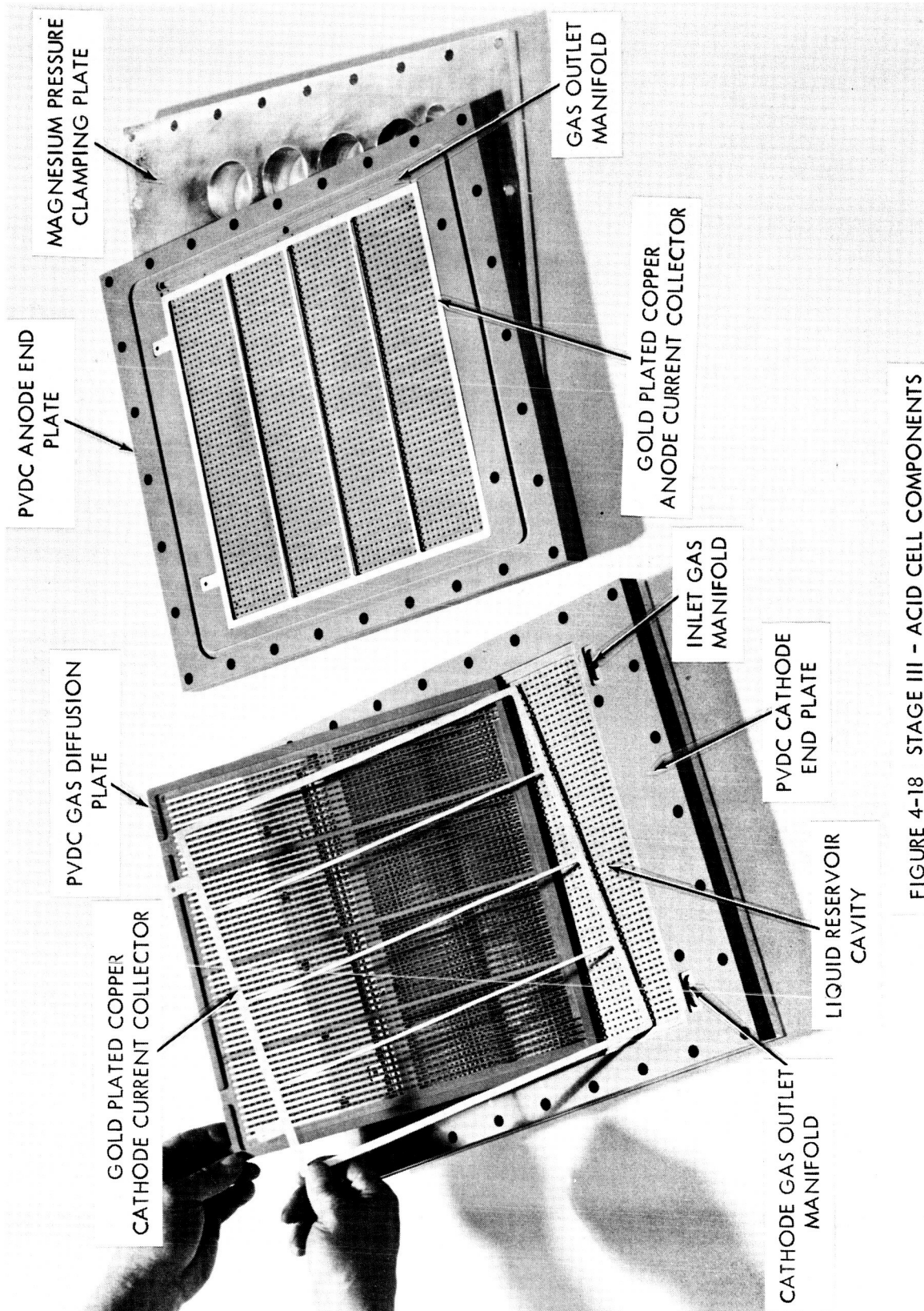


FIGURE 4-18 STAGE III - ACID CELL COMPONENTS

5.0 OBJECTIVES

During the final reporting period, it is anticipated that the following objectives will be attained:

1. Additional small acid cell tests will be completed.
2. Parametric tests on all three large cell stages will be completed.
3. A thermal balance study on the three stages will be completed.
4. A life test of two cells for each of the three stages will be completed.
5. The final technical report will be submitted to NASA.

6.0 CONCLUSIONS

Based on test data obtained to date the following conclusions were made:

1. Performance of the Stage I cell meets or exceeds performance predictions based on past tests with TRW plastic laboratory cells.
2. Wide variations in Stage I cell operating conditions can be tolerated without irreversible cell performance degradation.
3. Cathode gas flow rate to the Stage I cathode need not be greater than $2 \times S_{CO_2}$ for satisfactory performance.
4. Operation of the Stage I cell at elevated temperatures is feasible.
5. Operation of the Stage I cell is feasible at current densities exceeding 45 ASF. The upper limit at elevated temperatures (140°F and above) has not been determined.
6. Non-porous-gold plated components will be satisfactory for Stage III cell parametric testing.
7. The gold plating is not the cause of the slight increase of voltage with time in the small acid cell tests. The tantalum screen electrode appears to be the basic problem.
8. Based on preliminary results of test M-3, long term operation of a Stage III acid cell is feasible.
9. Additional detailed materials studies for acid stage flight configuration cells are required. These studies are required for three components:
 - a. Electrolyte matrix
 - b. Electrode base screen material
 - c. Low cost, low weight, acid resistant cell end plate.